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# (12) United States Patent
**Butt et al.**

(10) **Patent No.: US 11,571,820 B2**
(45) **Date of Patent: Feb. 7, 2023**

(54) **APPARATUS AND METHOD FOR CONTROLLING AN END-EFFECTOR ASSEMBLY**

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**Related U.S. Application Data**

(63) Continuation of application No. 14/262,221, filed on Apr. 25, 2014, now Pat. No. 10,471,607, which is a

(Continued)

(51) **Int. Cl.**
***B25J 18/00*** (2006.01)
***A61B 34/00*** (2016.01)

(Continued)

(52) **U.S. Cl.**
CPC .............. ***B25J 18/00*** (2013.01); ***A61B 34/70*** (2016.02); *A61B 2017/00309* (2013.01);

(Continued)

(58) **Field of Classification Search**
CPC .... B25J 18/00; B25J 15/0206; B25J 15/0213; A61B 34/70; A61B 2034/301;

(Continued)

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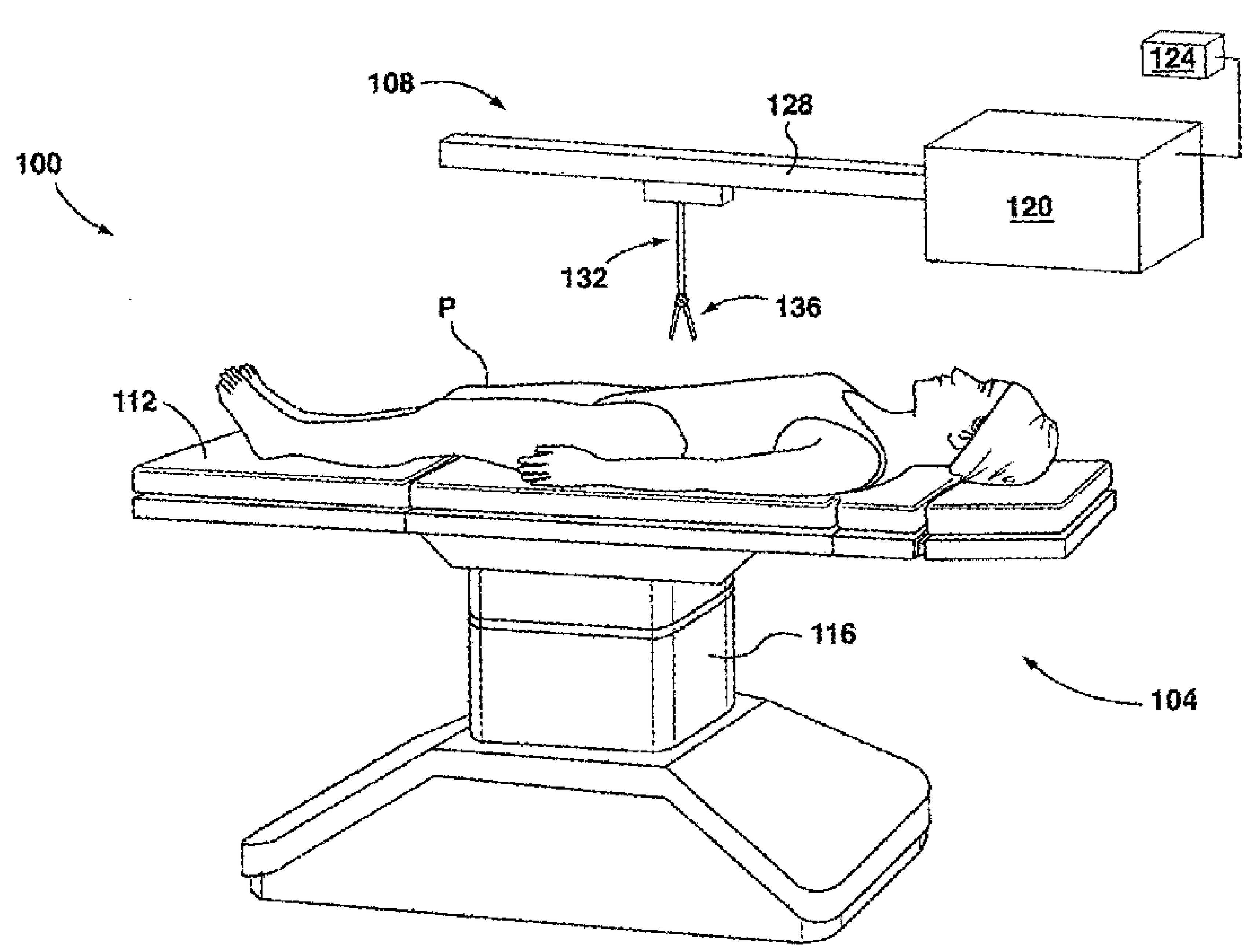
(57) **ABSTRACT**

An apparatus for controlling an end-effector assembly is provided. The apparatus includes a elongated element configured to engage the end-effector assembly and a drive assembly. A first motion transfer mechanism is disposed at an end of the elongated element. The first motion transfer mechanism is configured to transfer a rotational motion of the elongated element to a motion of the end-effector assembly. A second motion transfer mechanism is disposed at the second end of the elongated element. The second motion transfer mechanism is configured to transfer a motion of the drive assembly to the rotational motion of the elongated element.

**18 Claims, 25 Drawing Sheets**



**Related U.S. Application Data**

continuation of application No. PCT/CA2011/001225, filed on Nov. 4, 2011.

(51) **Int. Cl.**

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|---|---|
| ***B25J 15/02*** | (2006.01) |
| ***A61B 34/30*** | (2016.01) |
| ***A61B 17/00*** | (2006.01) |
| ***A61B 17/29*** | (2006.01) |

(52) **U.S. Cl.**

CPC ............... *A61B 2017/00314* (2013.01); *A61B 2017/00526* (2013.01); *A61B 2017/2905* (2013.01); *A61B 2017/2908* (2013.01); *A61B 2017/2927* (2013.01); *A61B 2034/301* (2016.02); *A61B 2034/305* (2016.02); *B25J 15/0206* (2013.01); *B25J 15/0213* (2013.01); *Y10S 901/23* (2013.01); *Y10T 74/20311* (2015.01); *Y10T 74/20329* (2015.01)

(58) **Field of Classification Search**

CPC .... A61B 2034/305; A61B 2017/00309; A61B 2017/00314; A61B 2017/00526; A61B 2017/2905; A61B 2017/2908; A61B 2017/2927; Y10T 74/20311; Y10T 74/20329; Y10S 901/23

See application file for complete search history.

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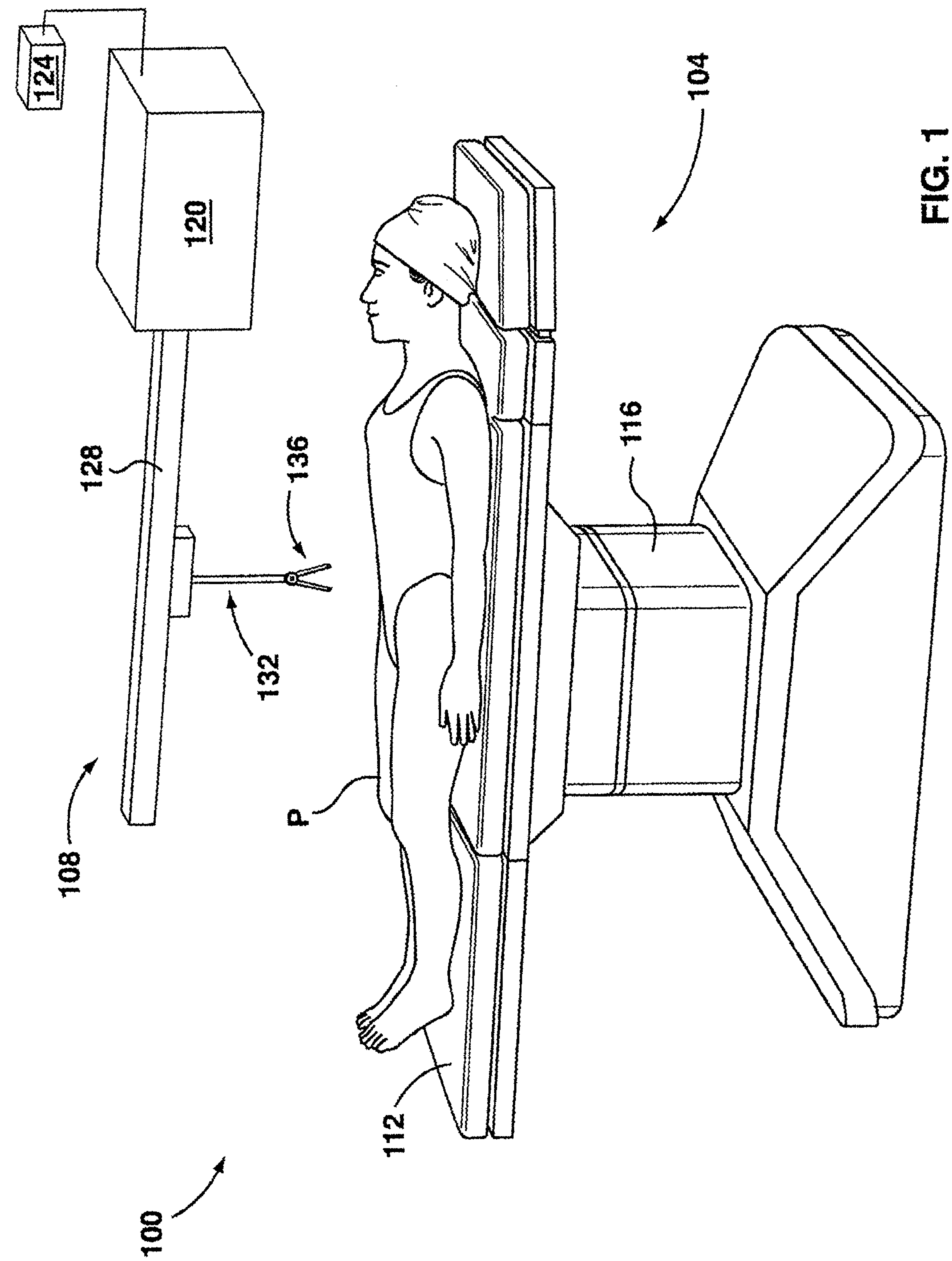



FIG. 1

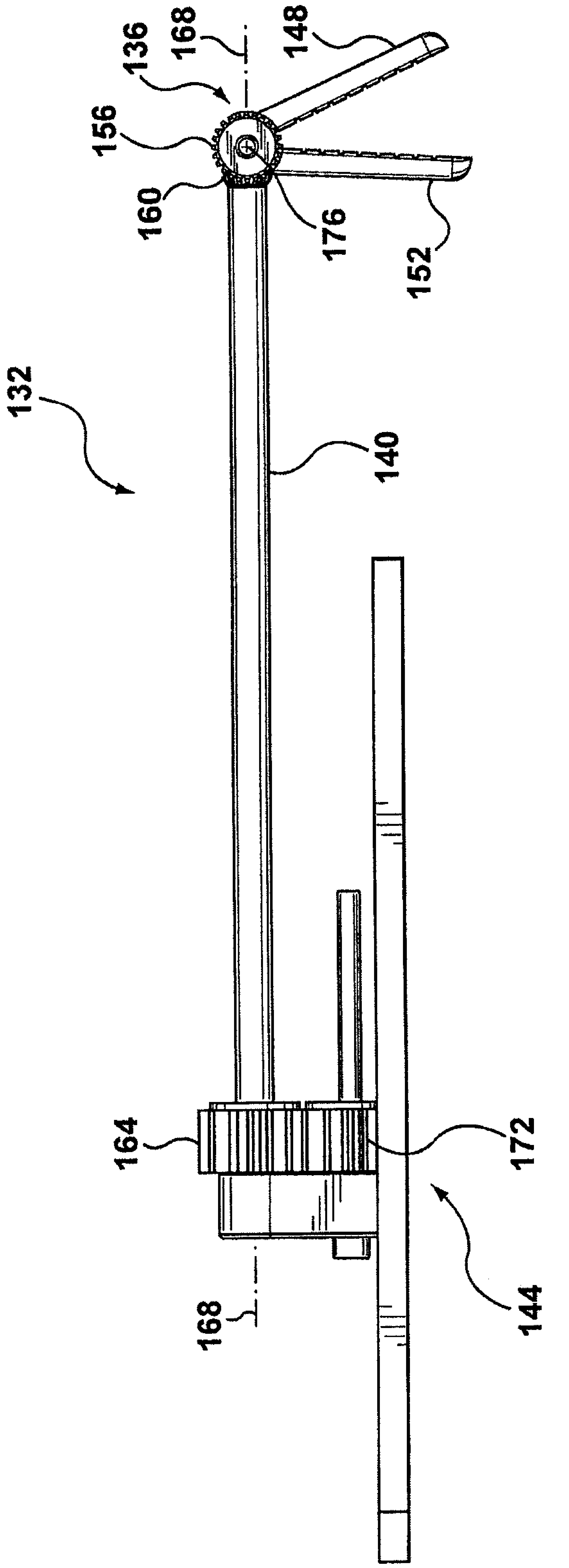
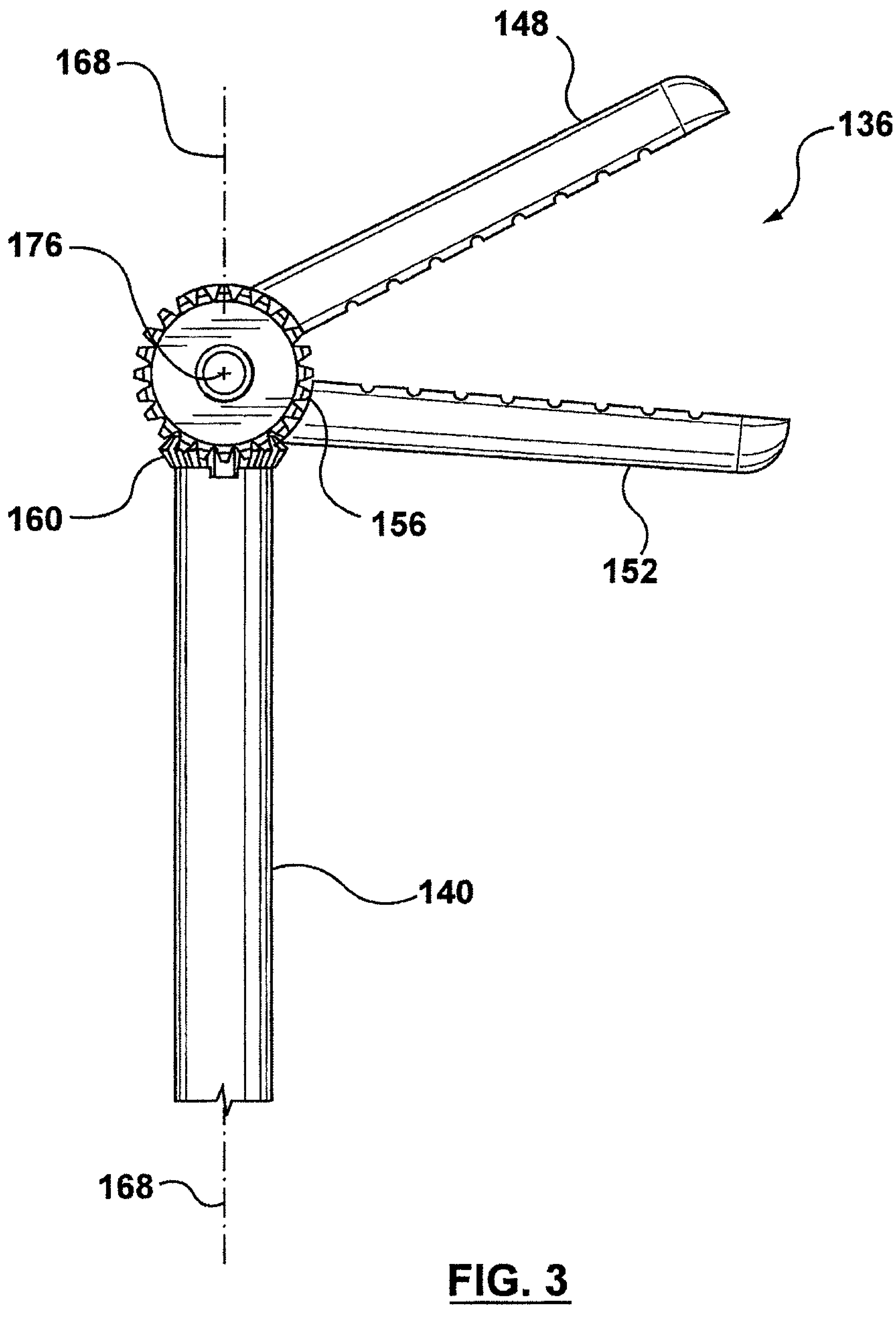



FIG. 2

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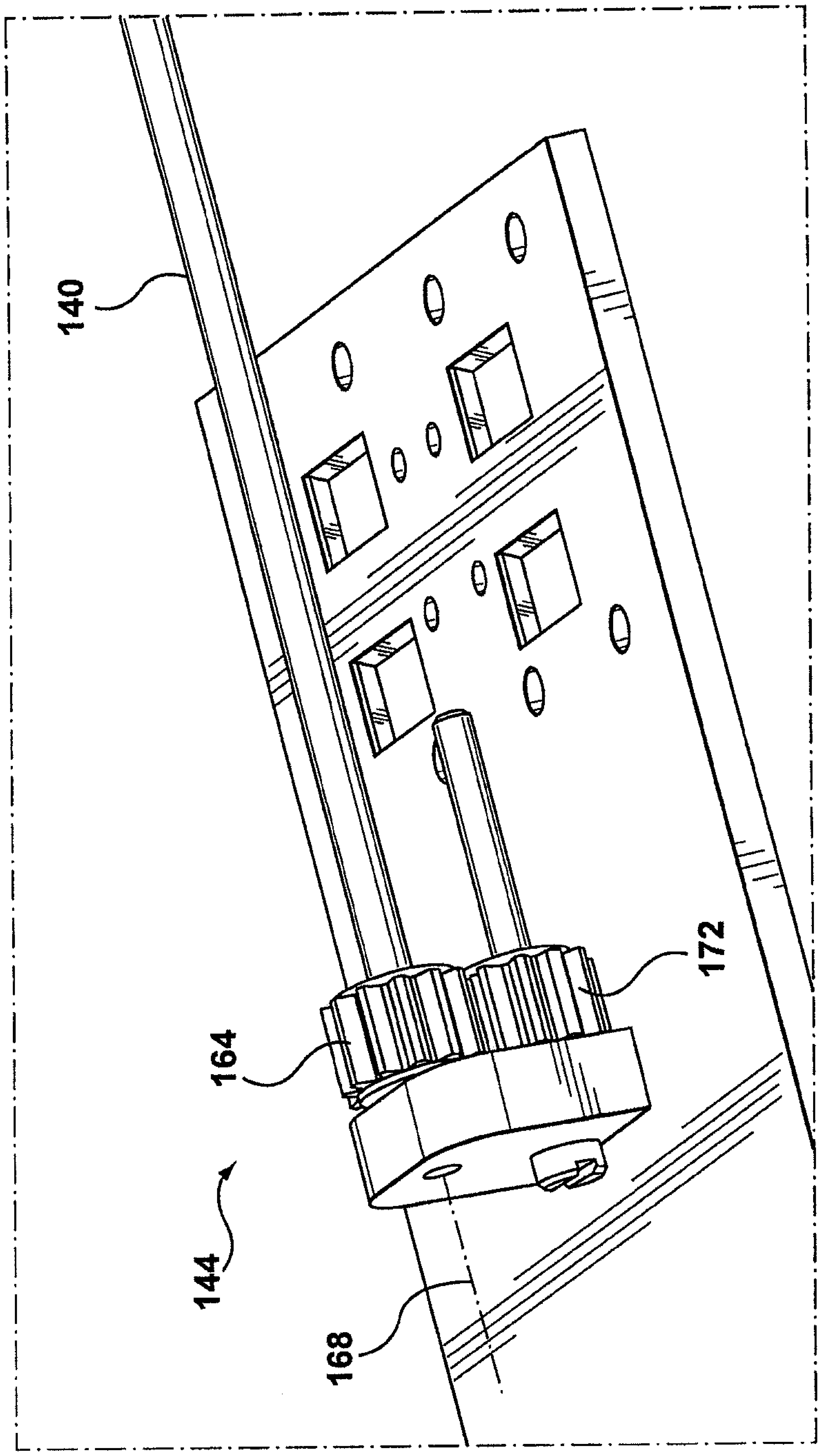


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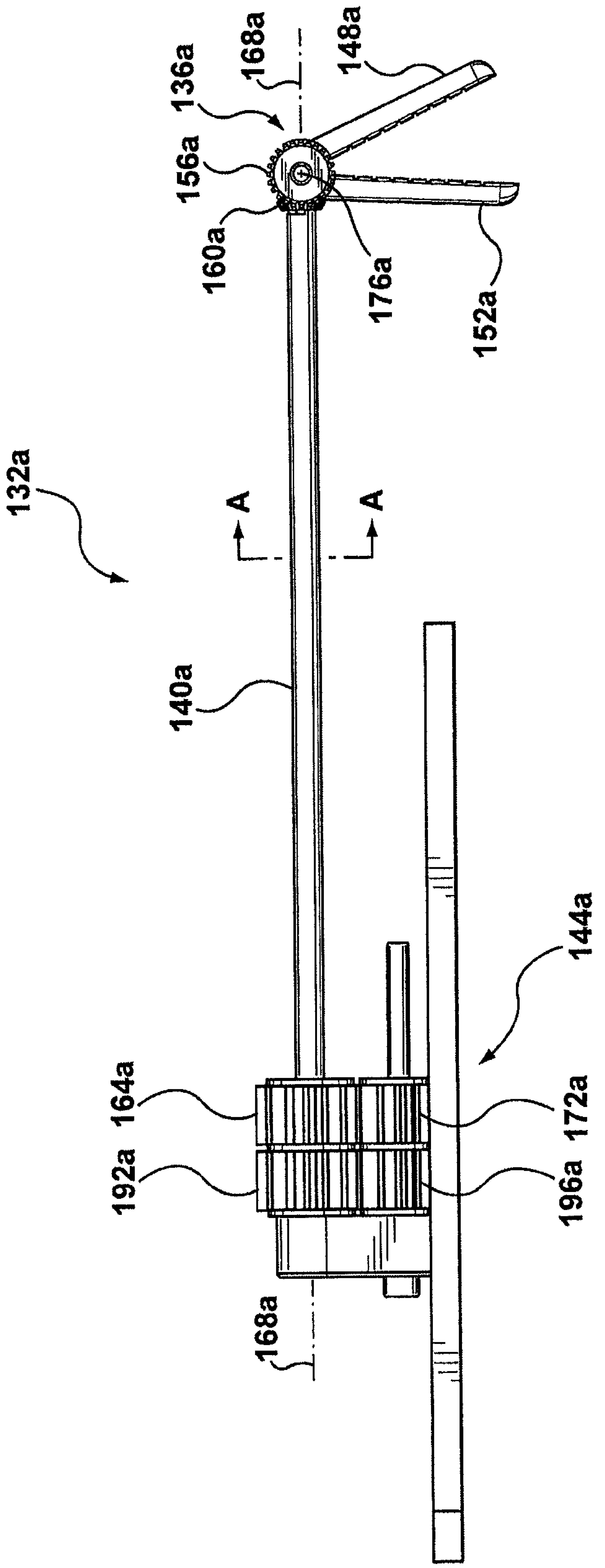
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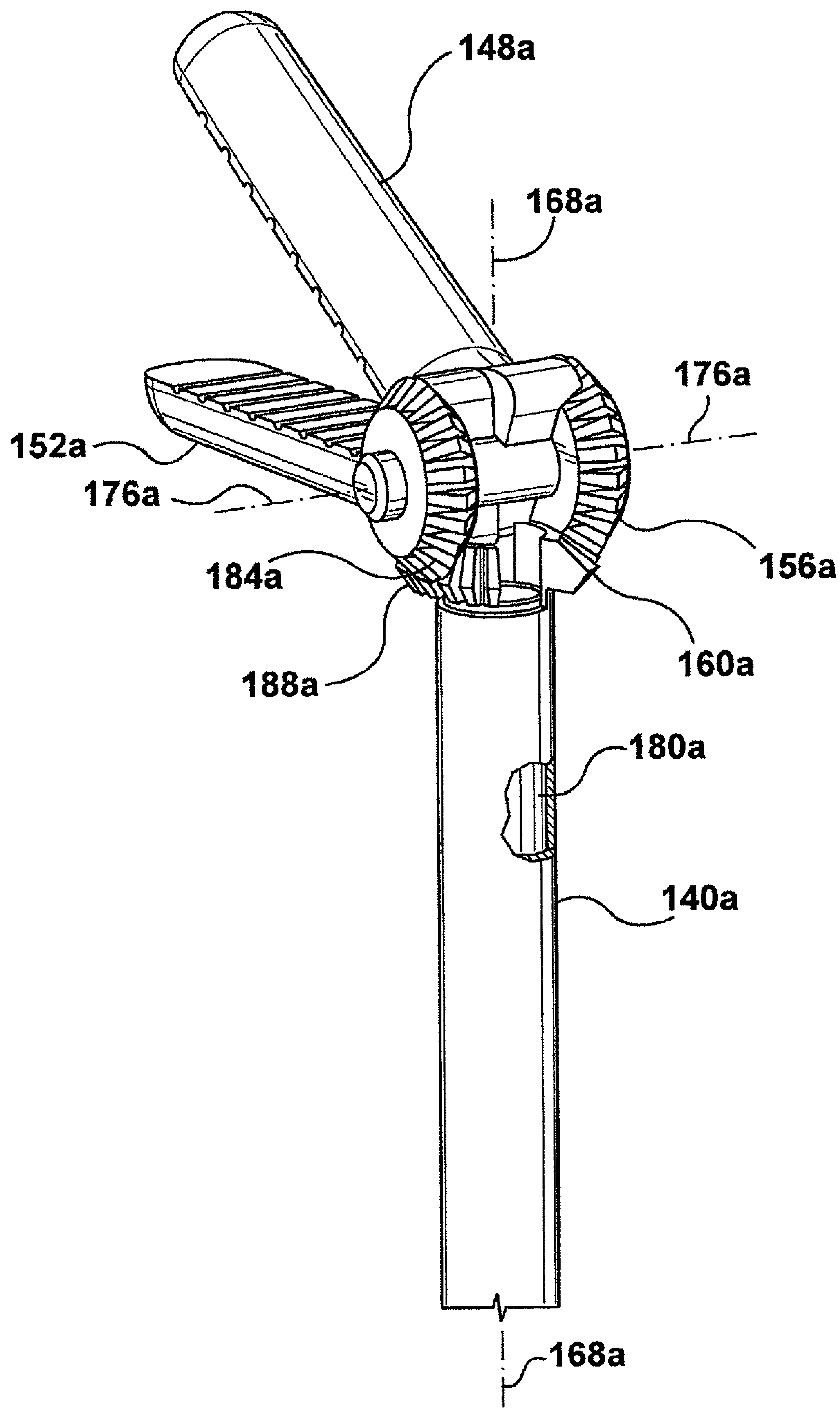


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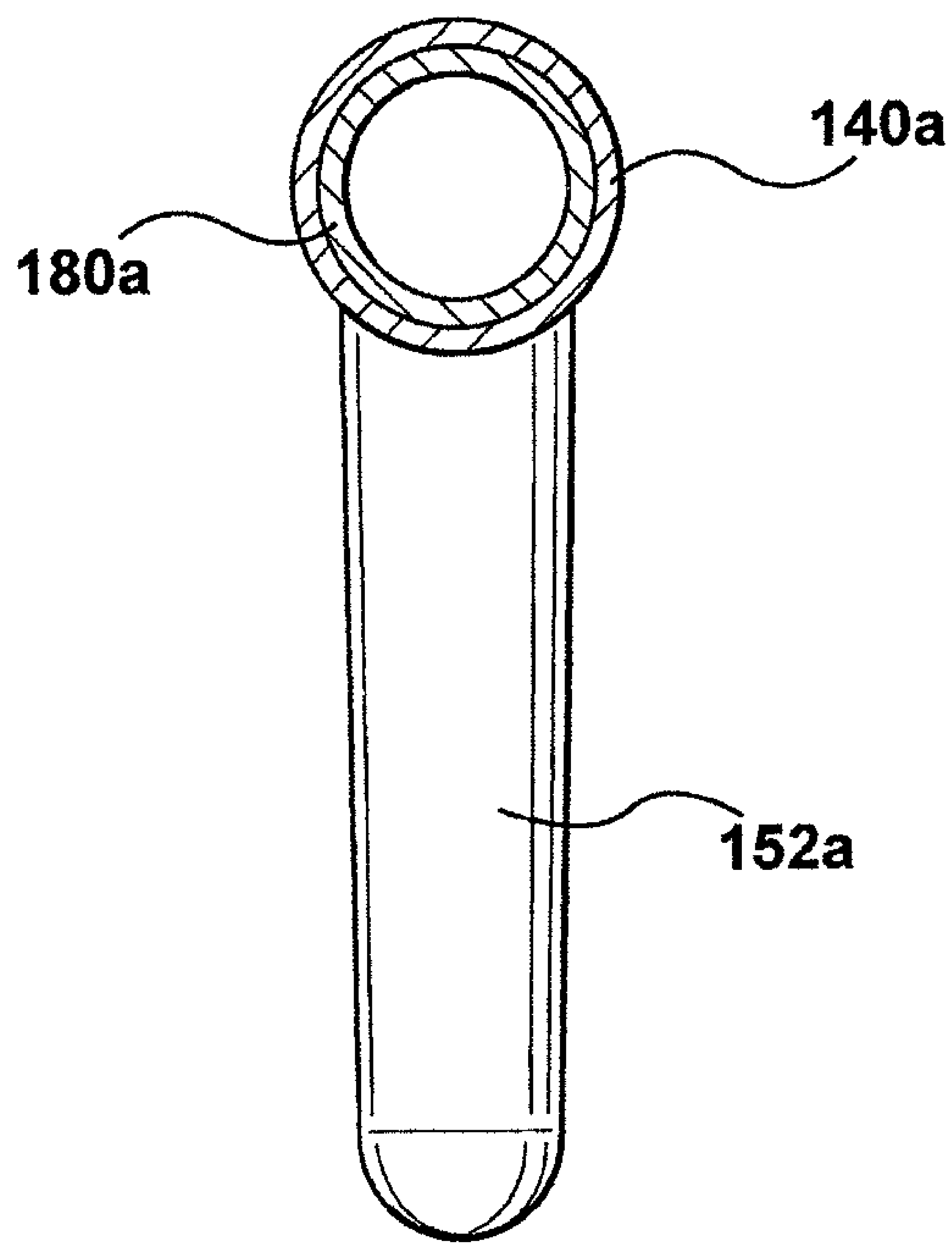


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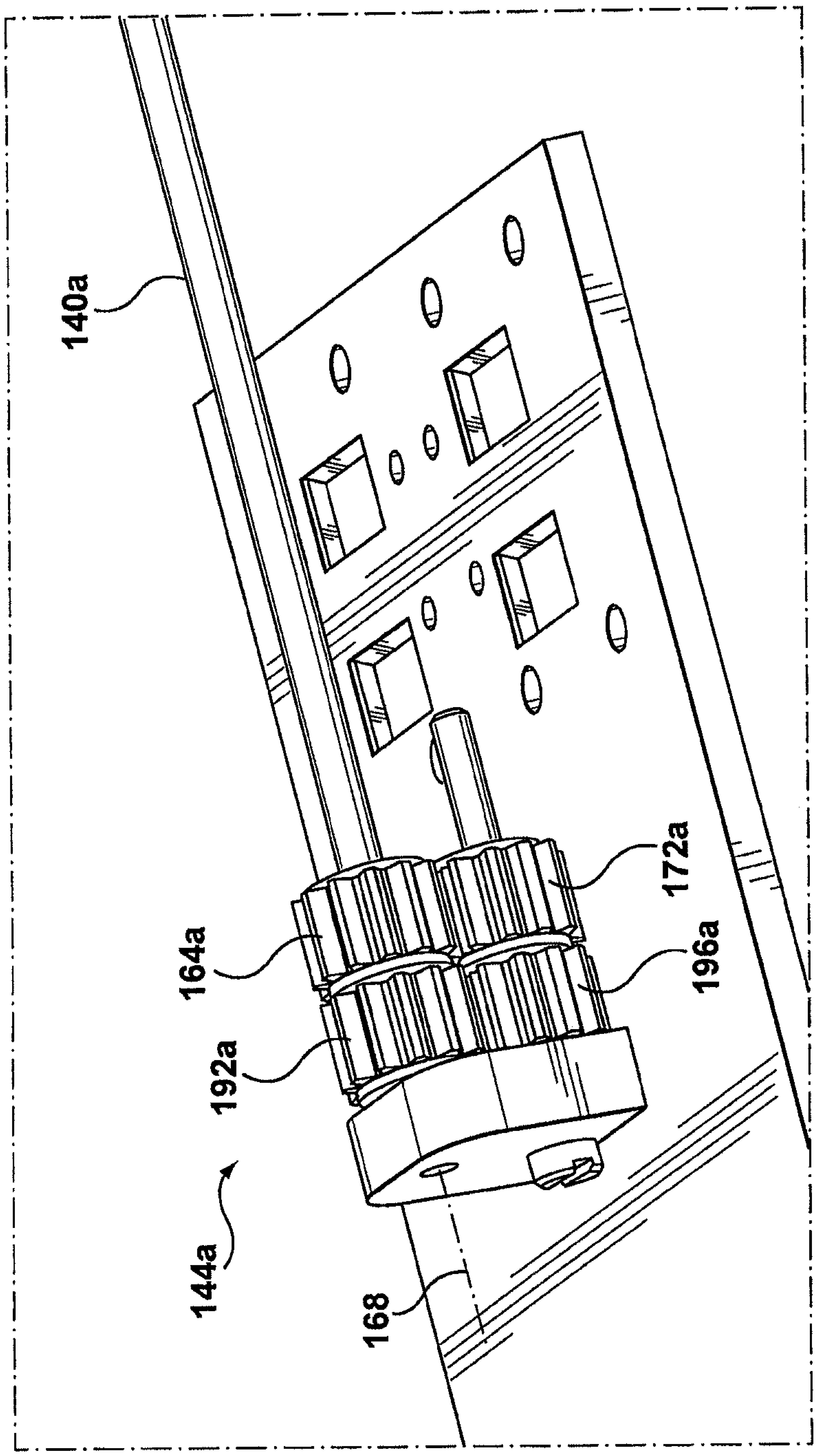


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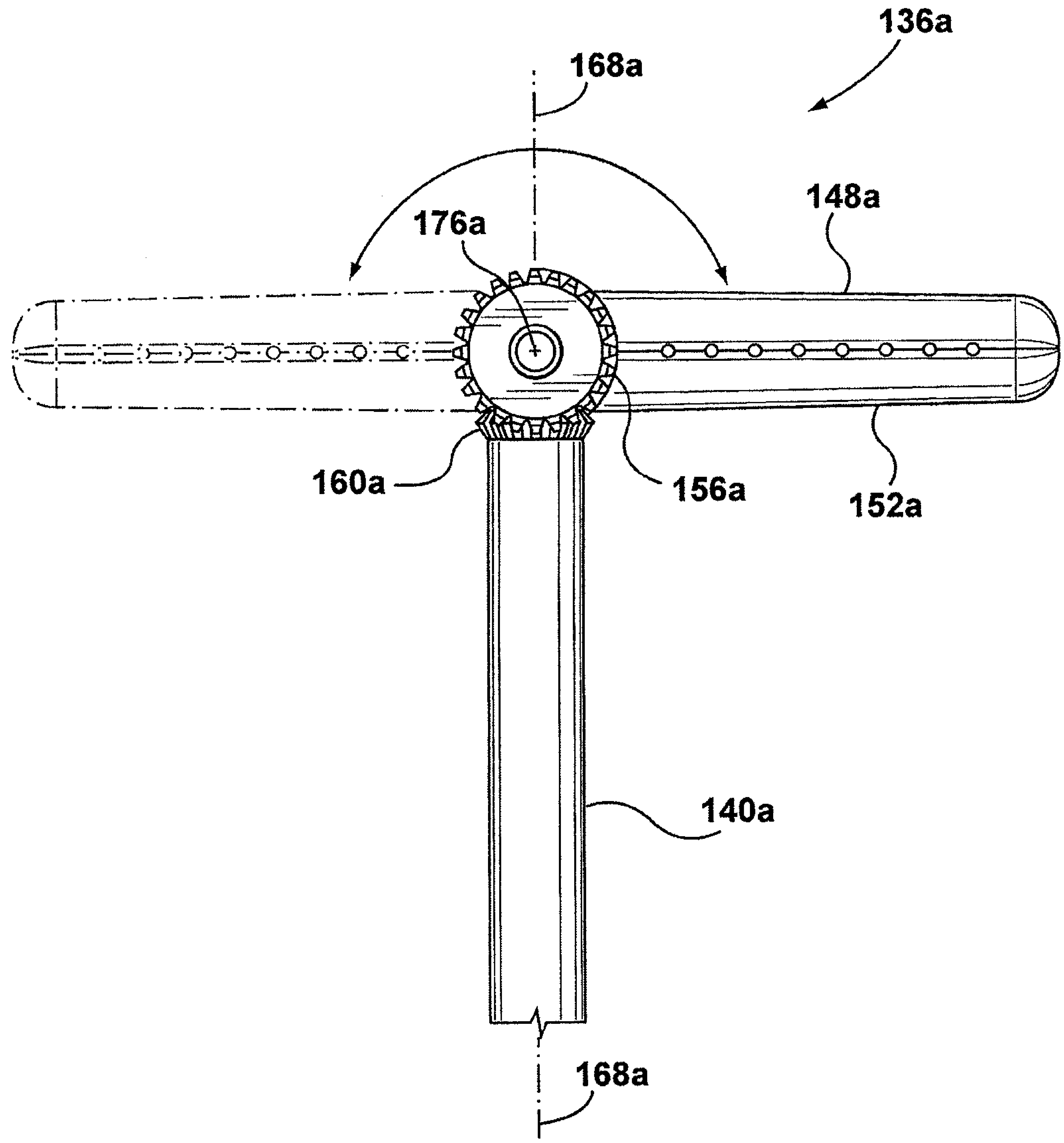


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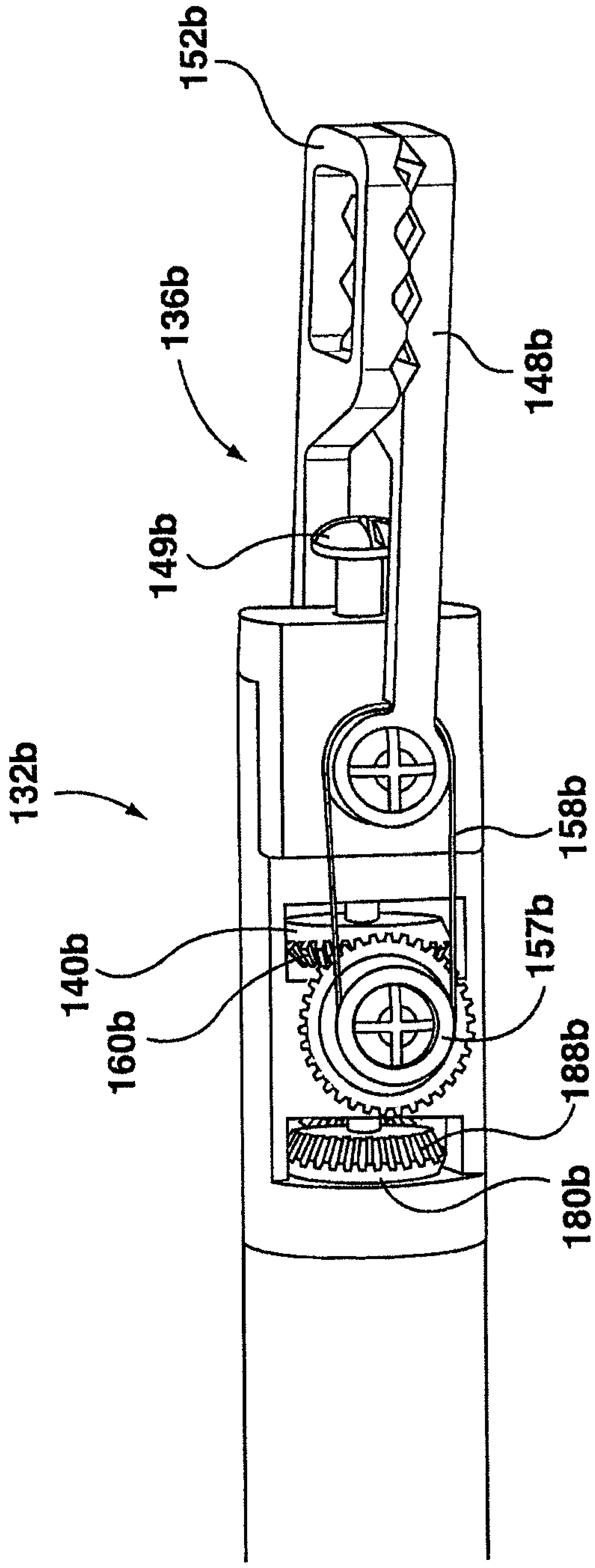


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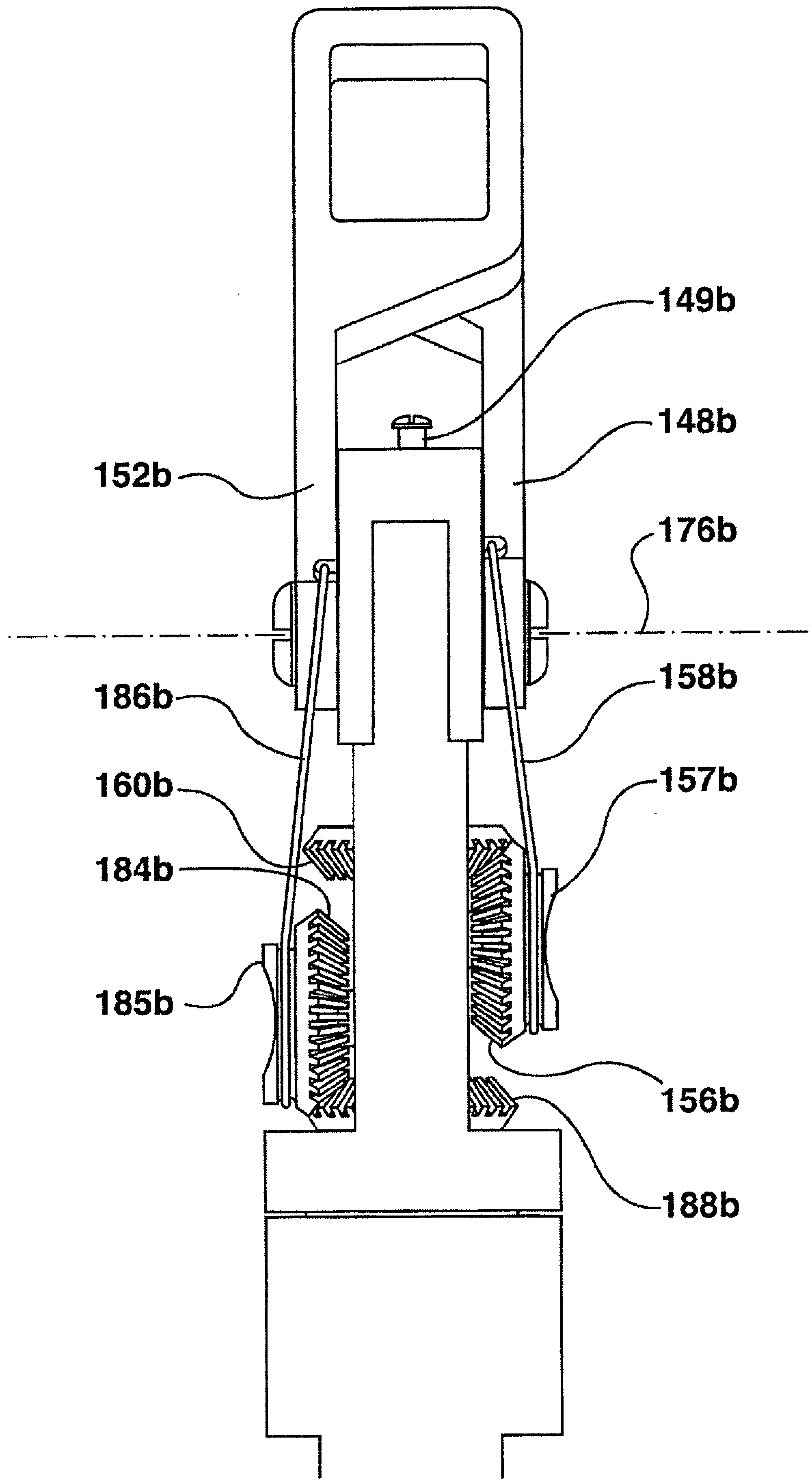


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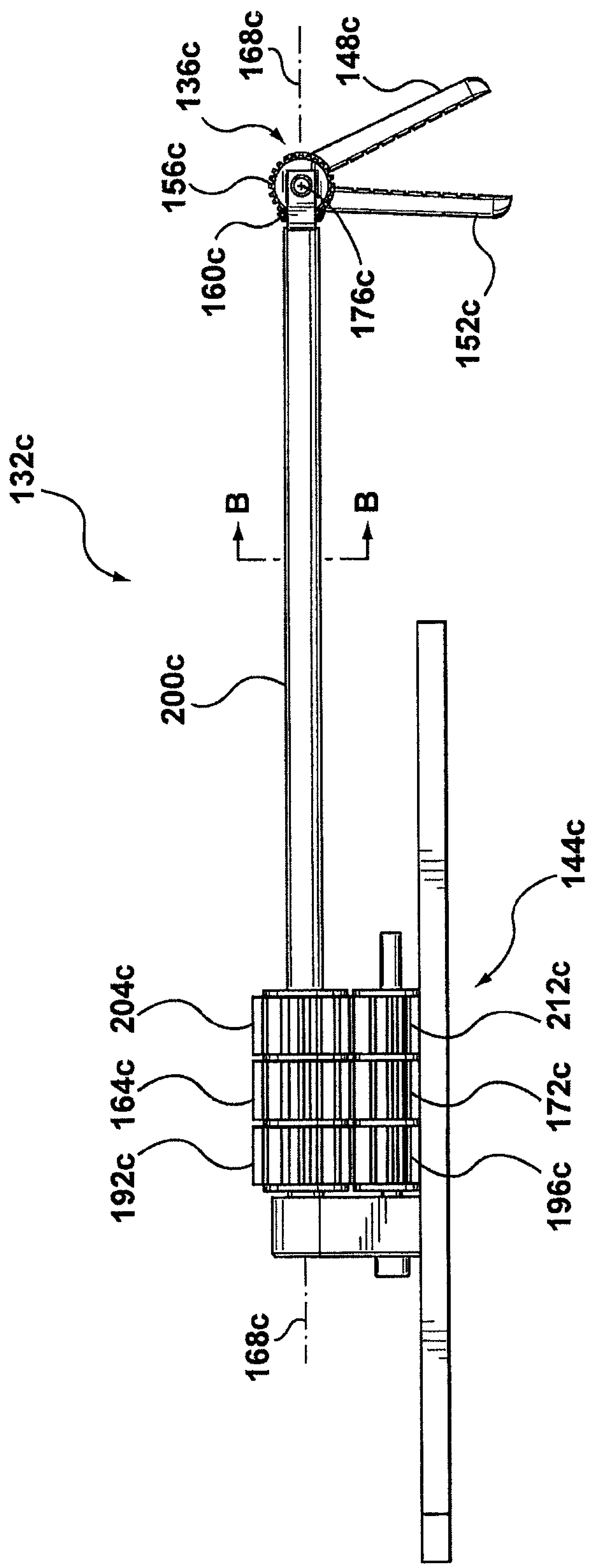
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FIG. 12

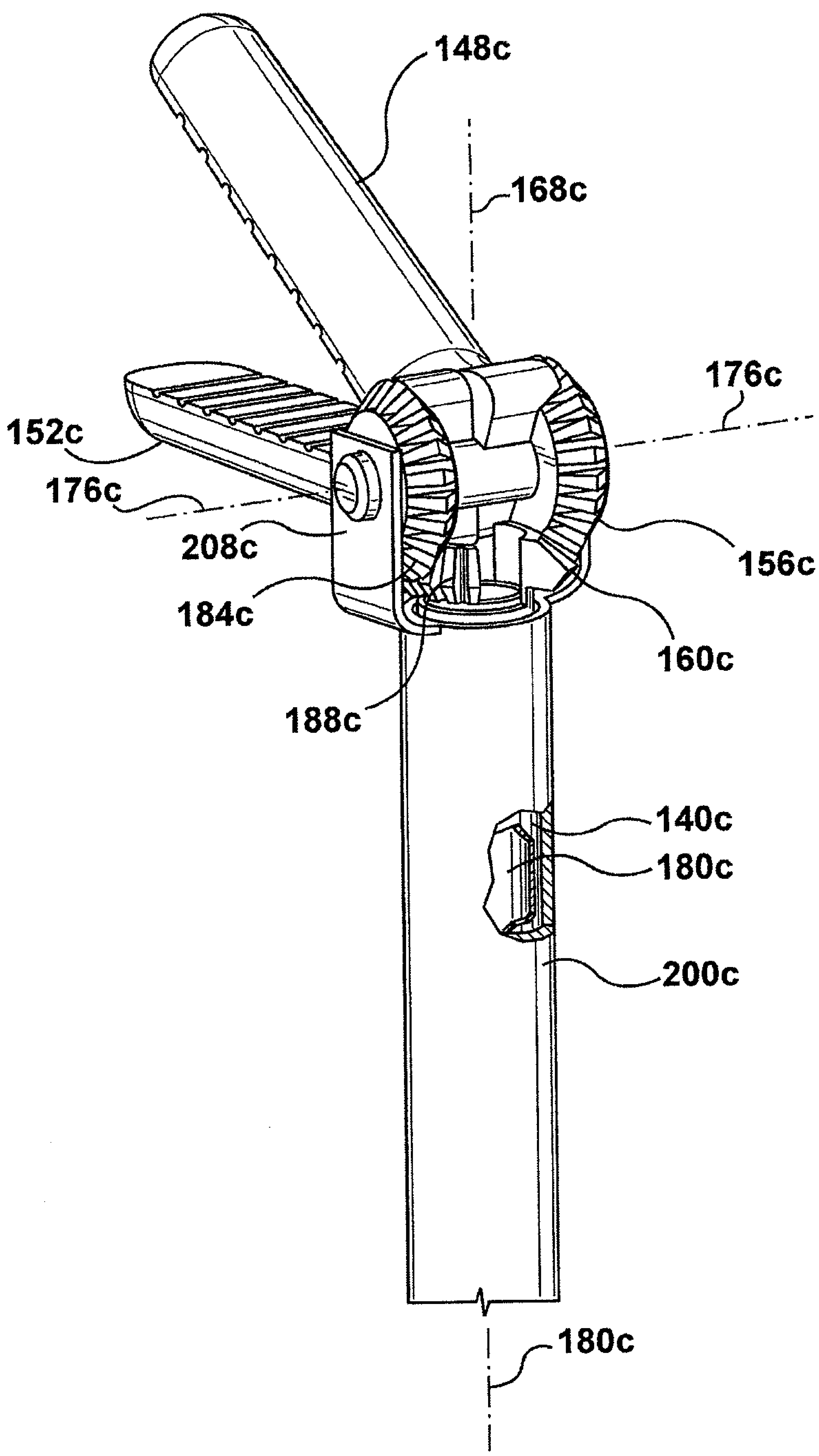
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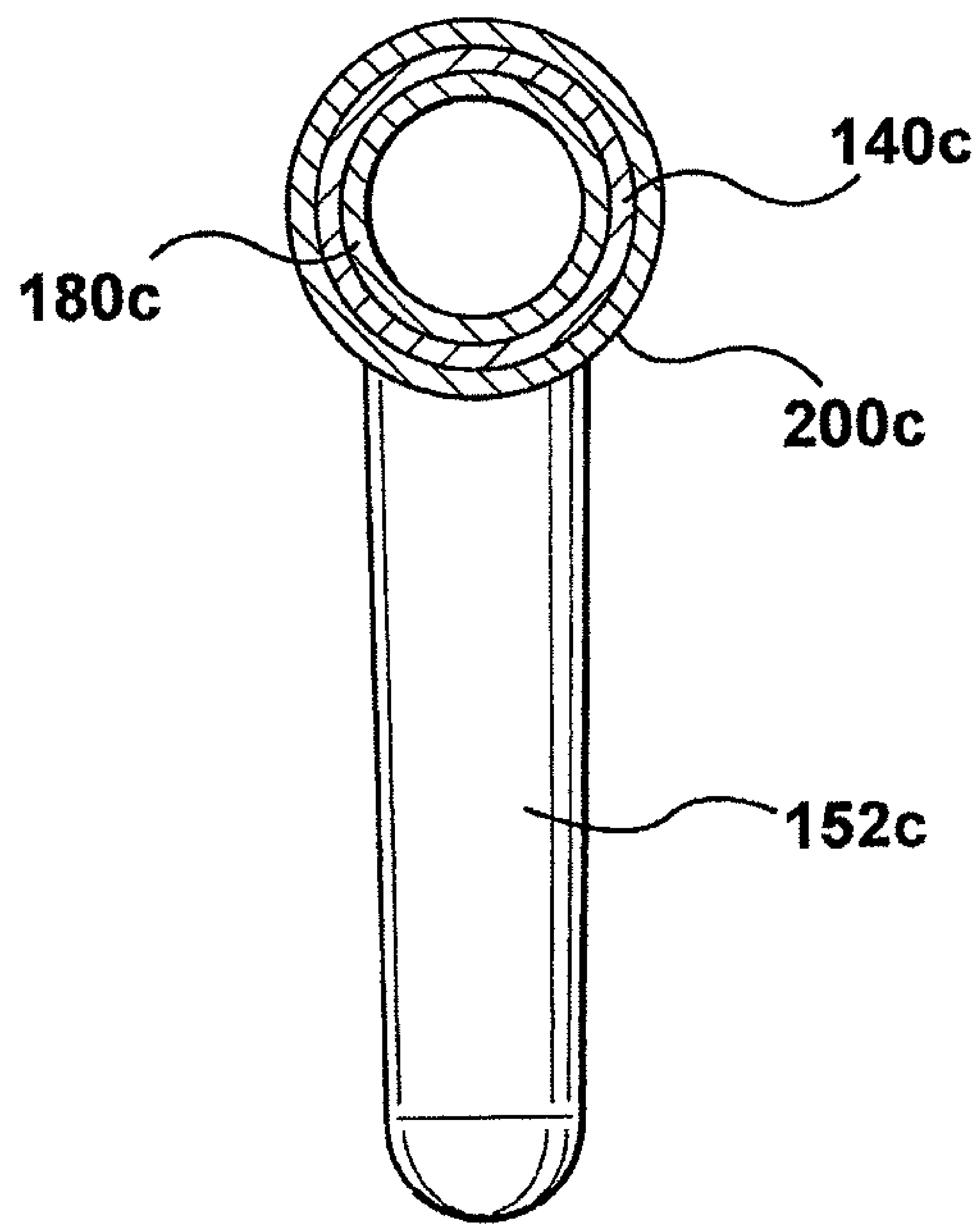
FIG. 13

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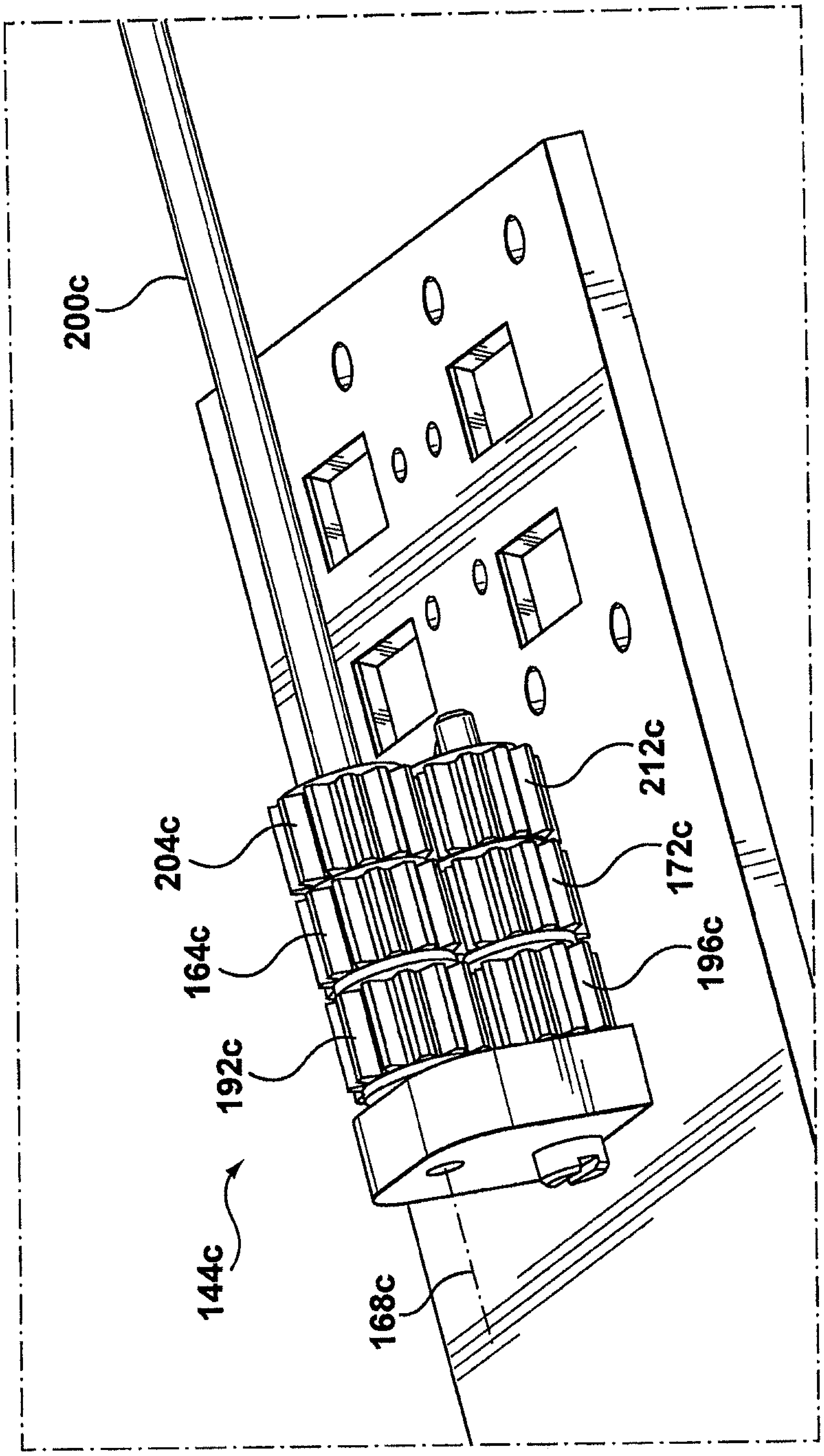


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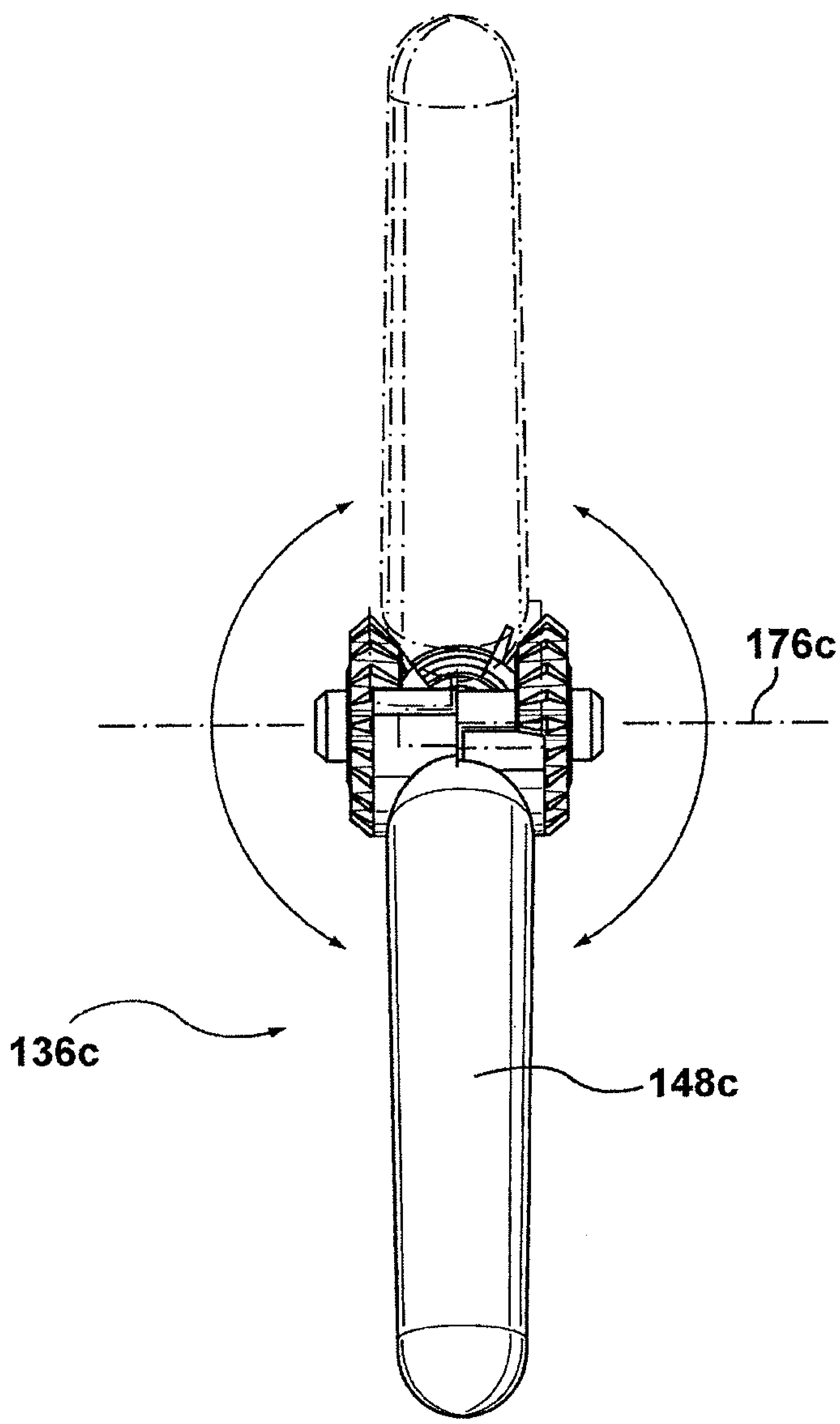


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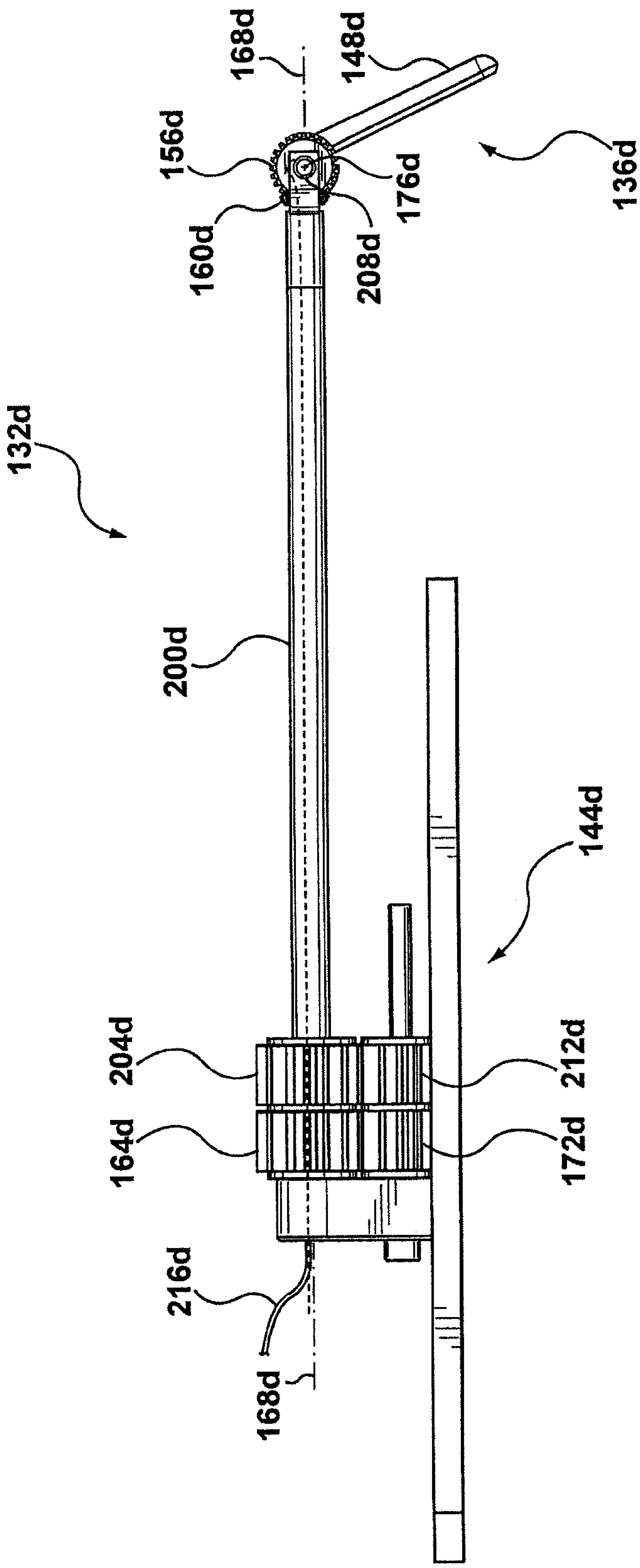
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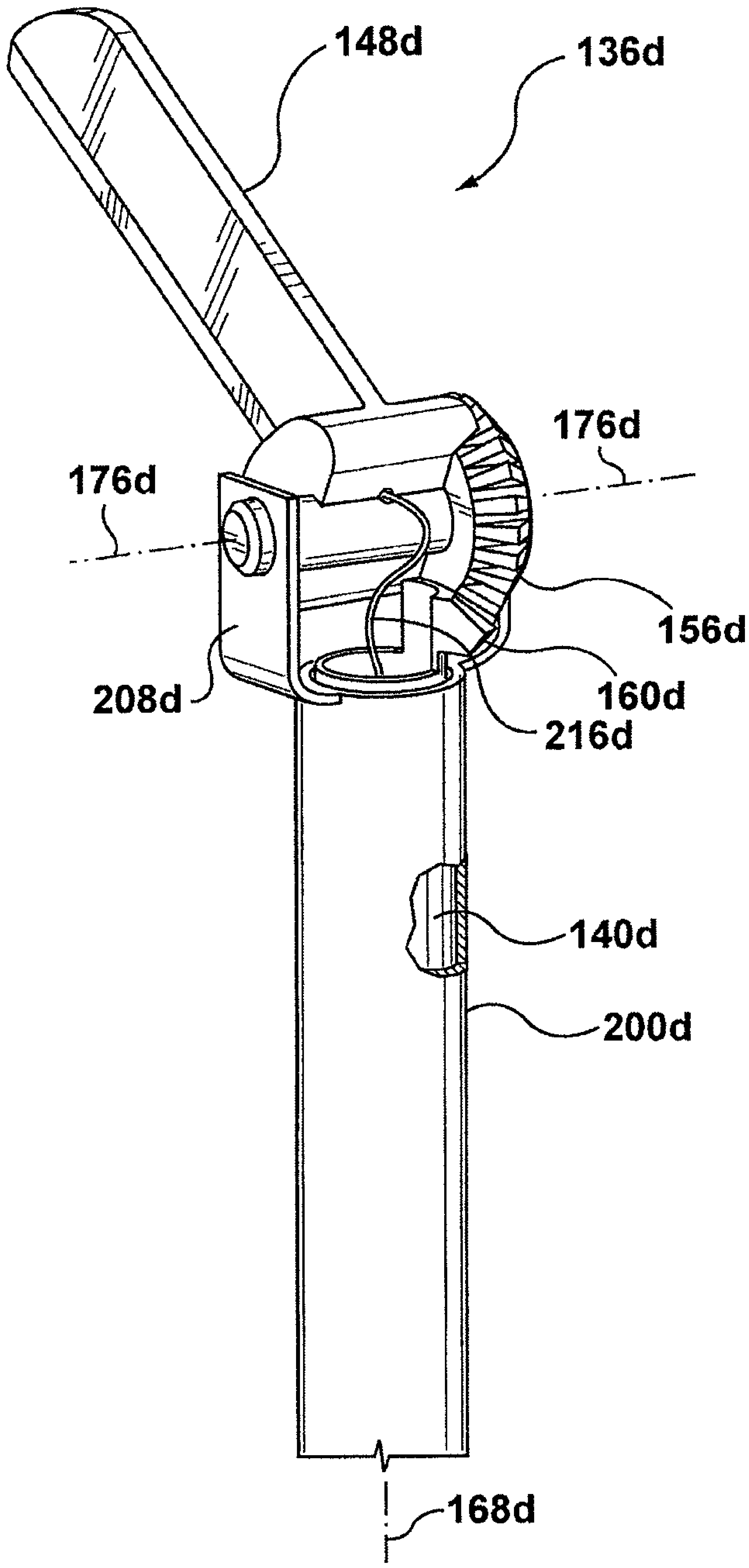
FIG. 17

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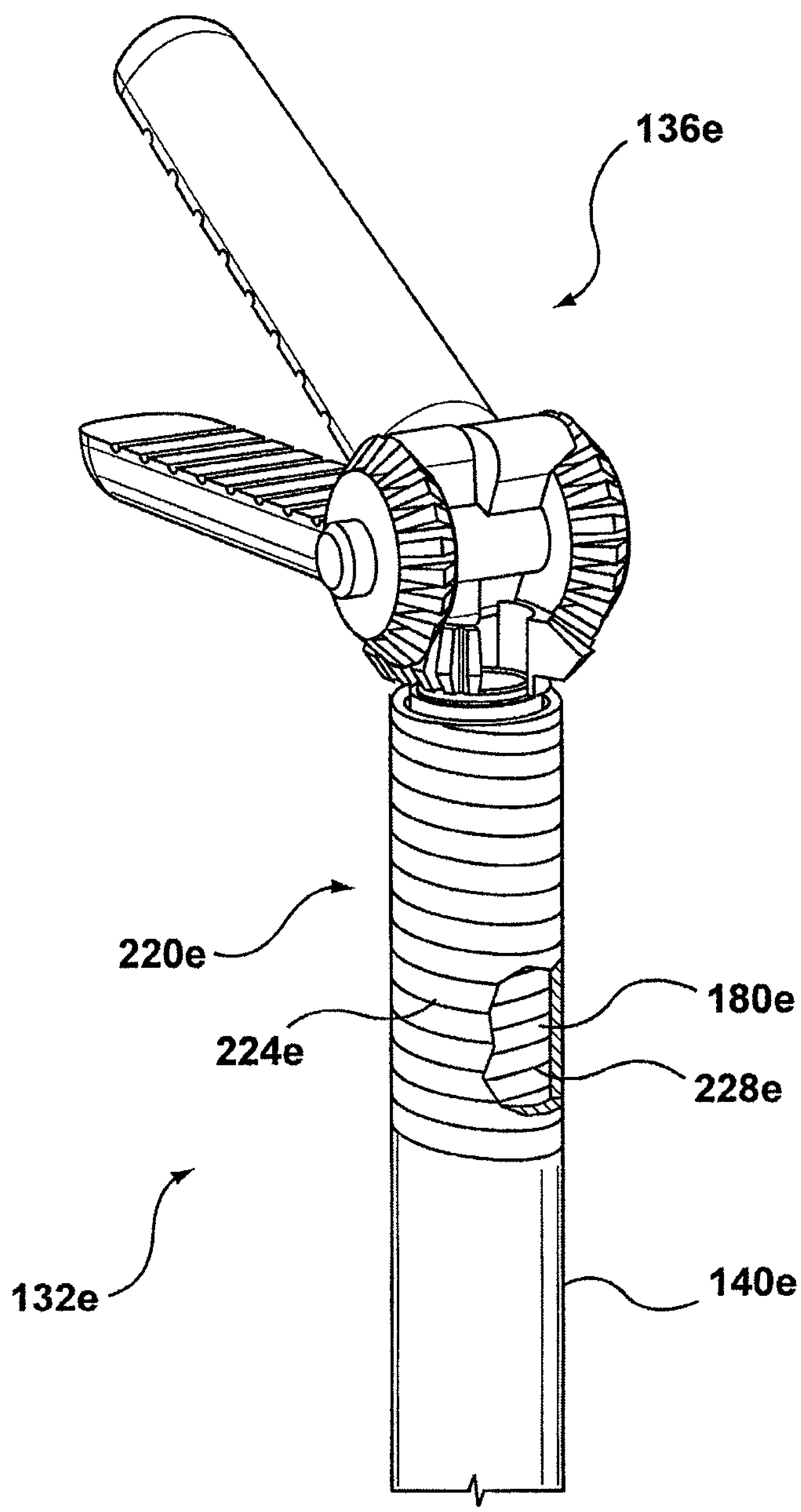



FIG. 19

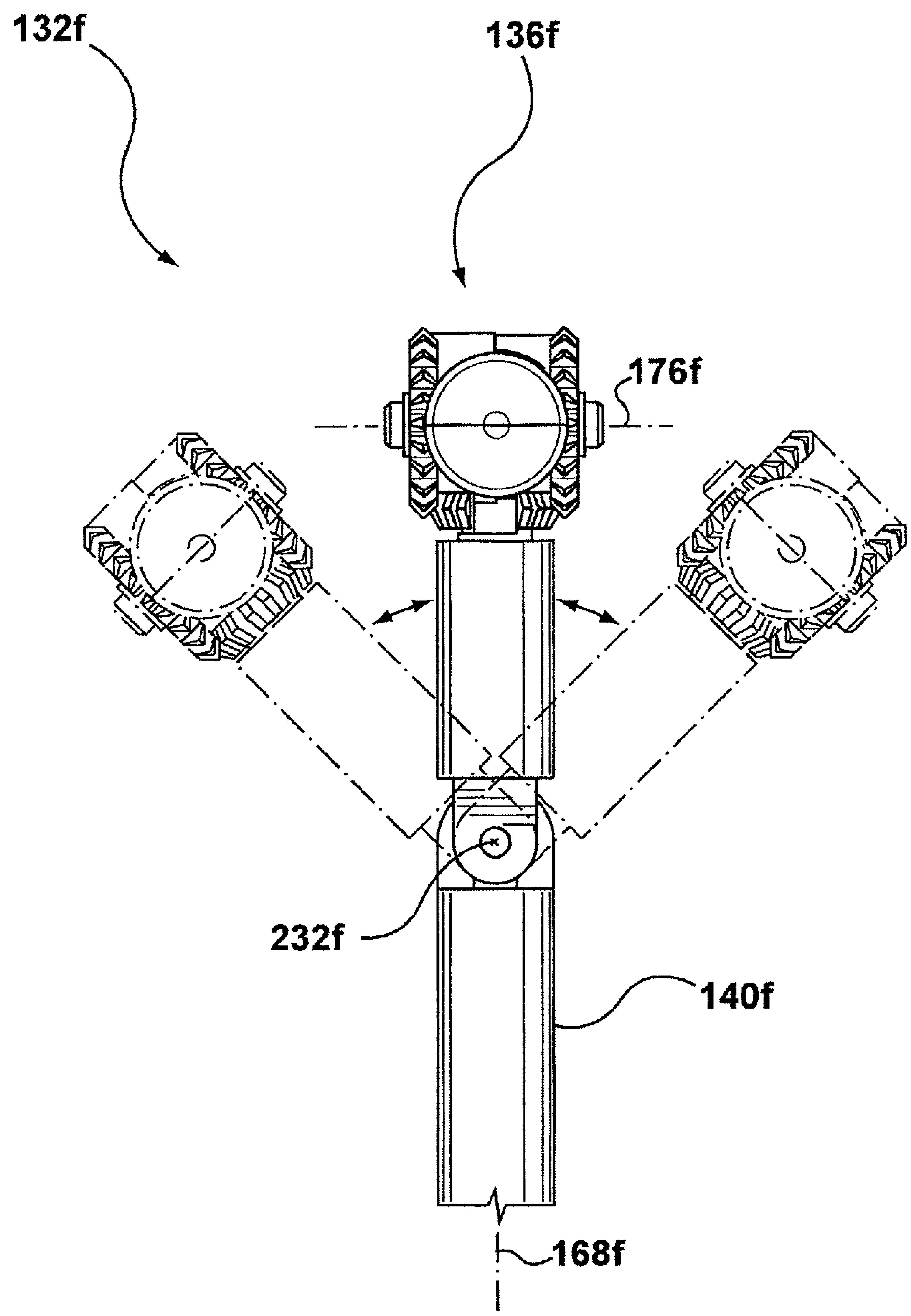
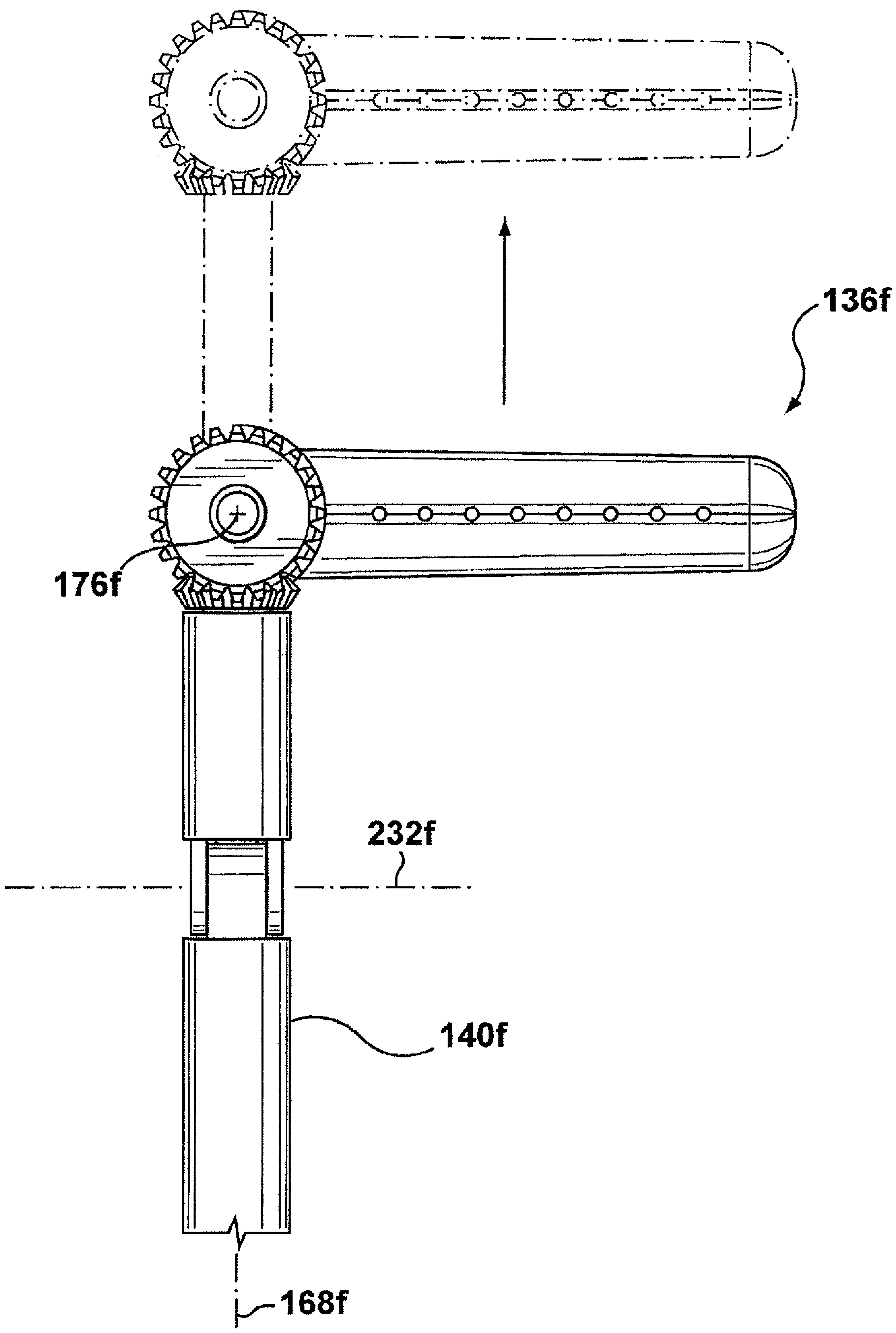



FIG. 20

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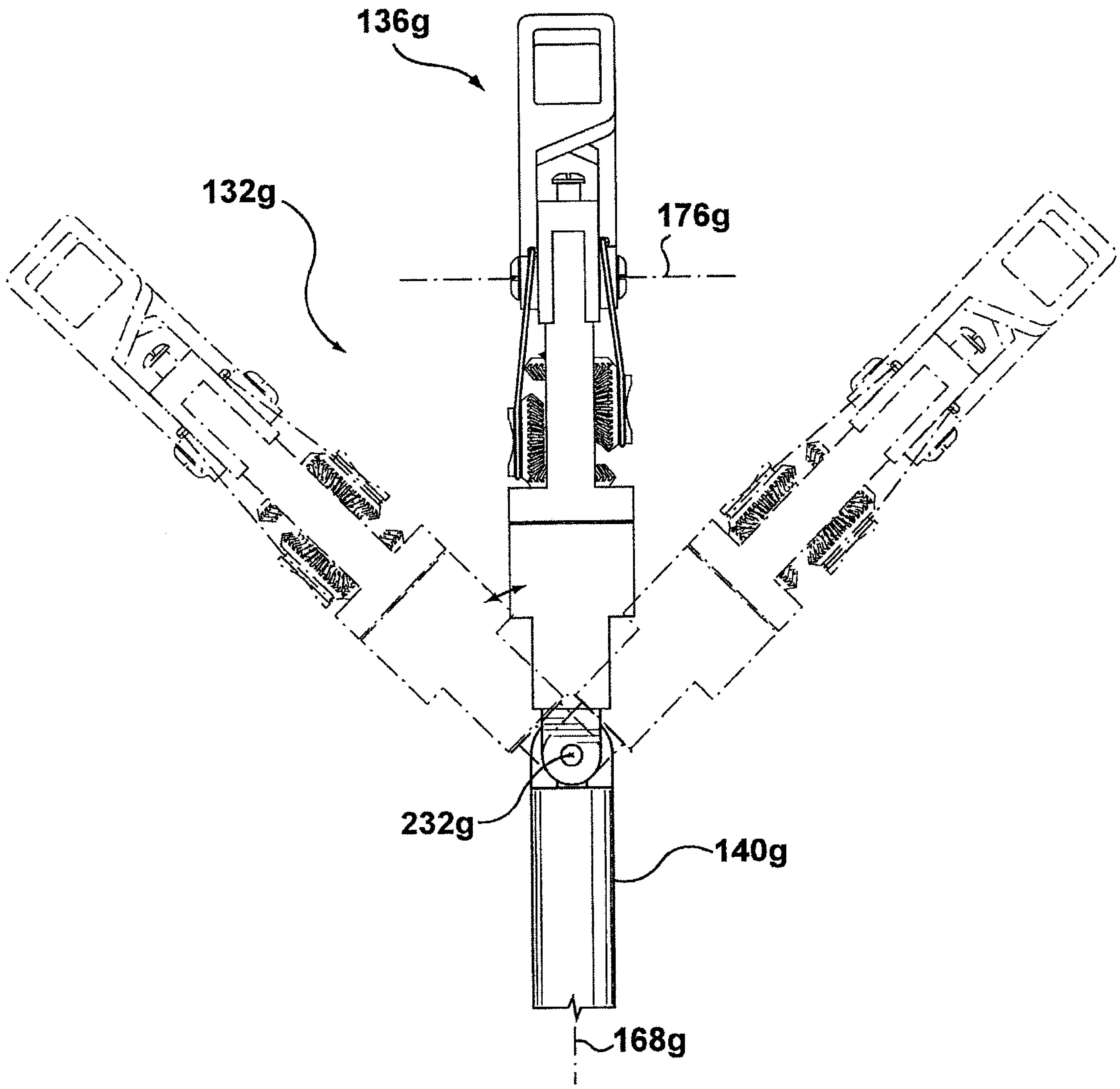


FIG. 22

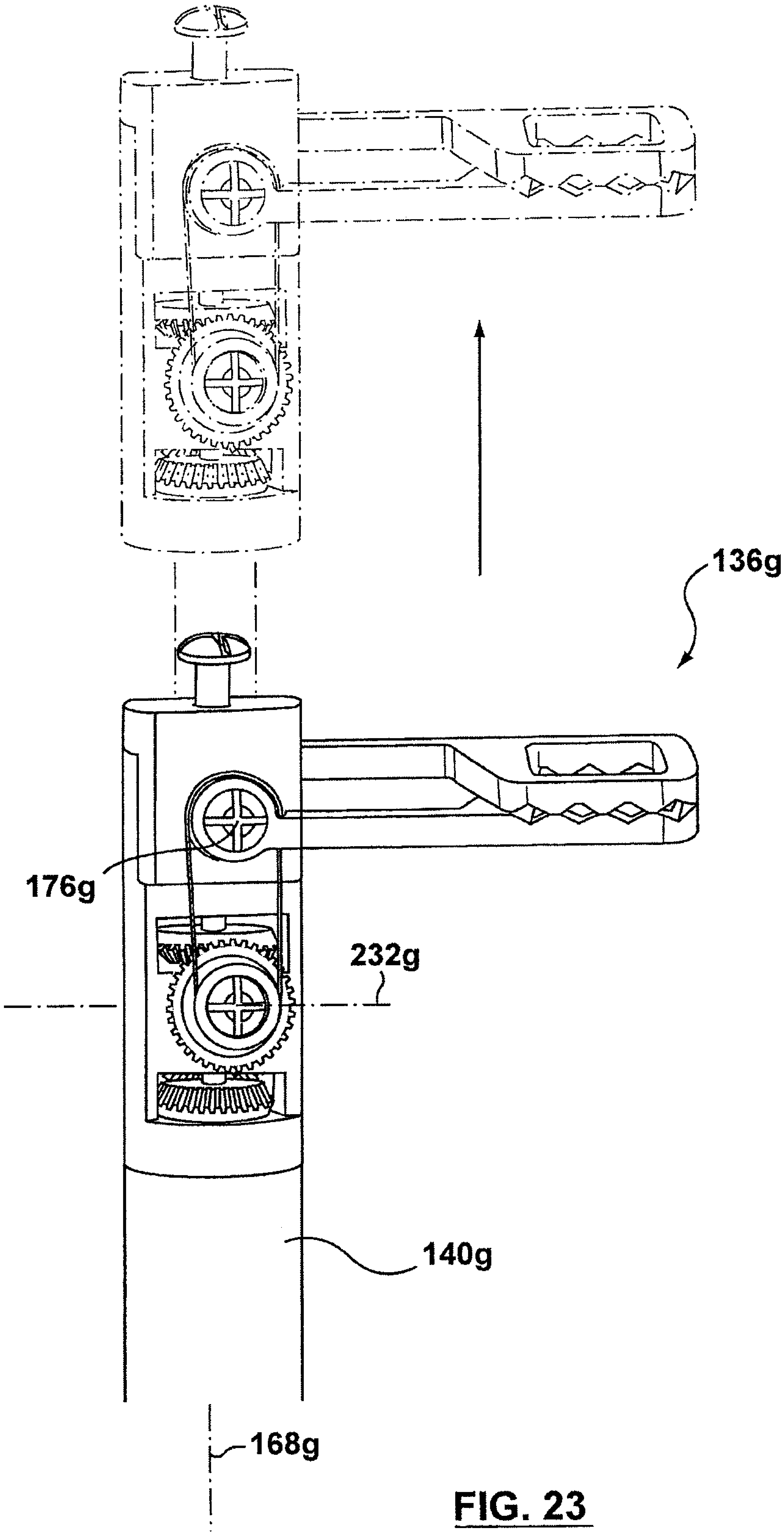


FIG. 23

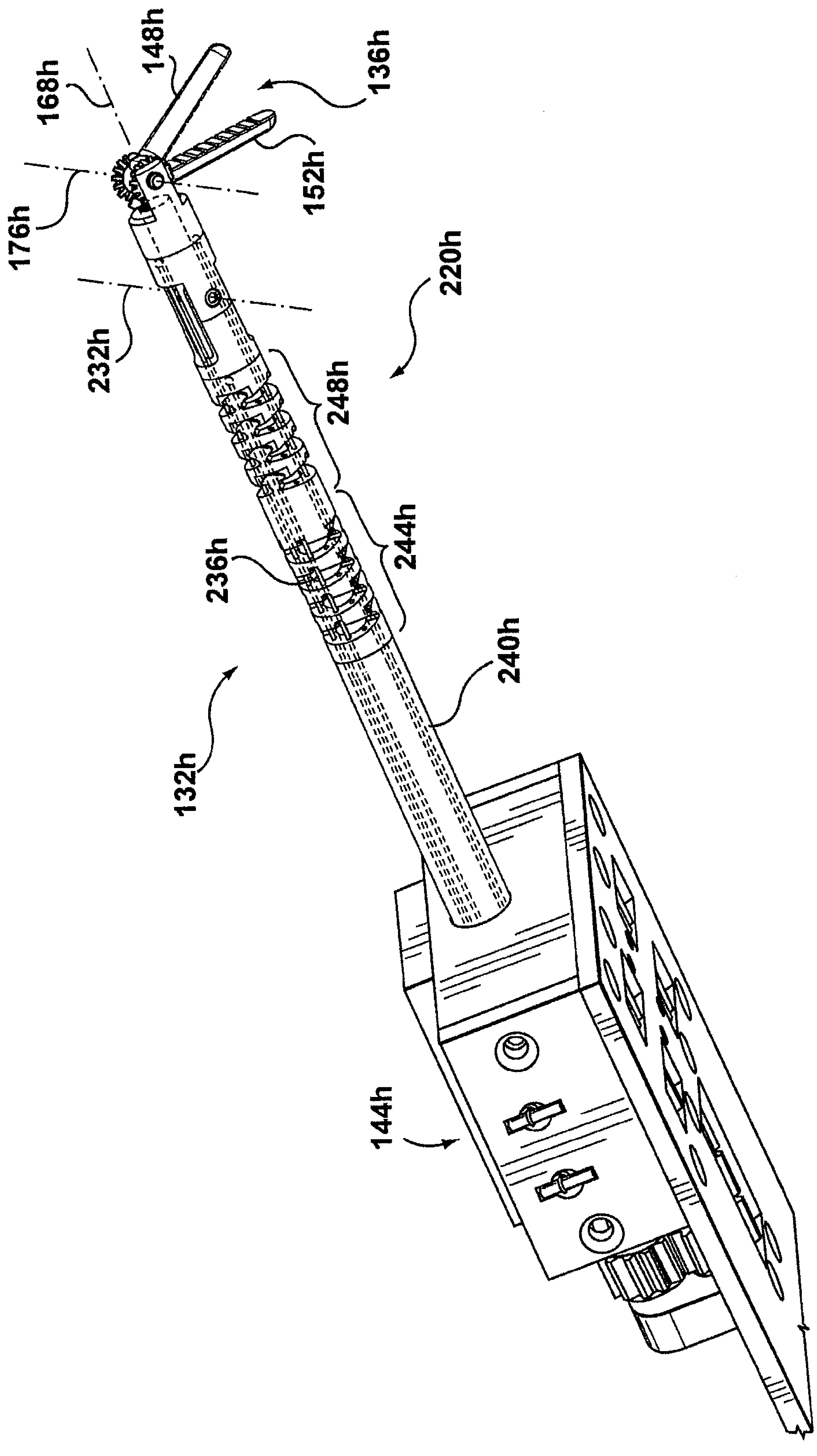
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FIG. 24

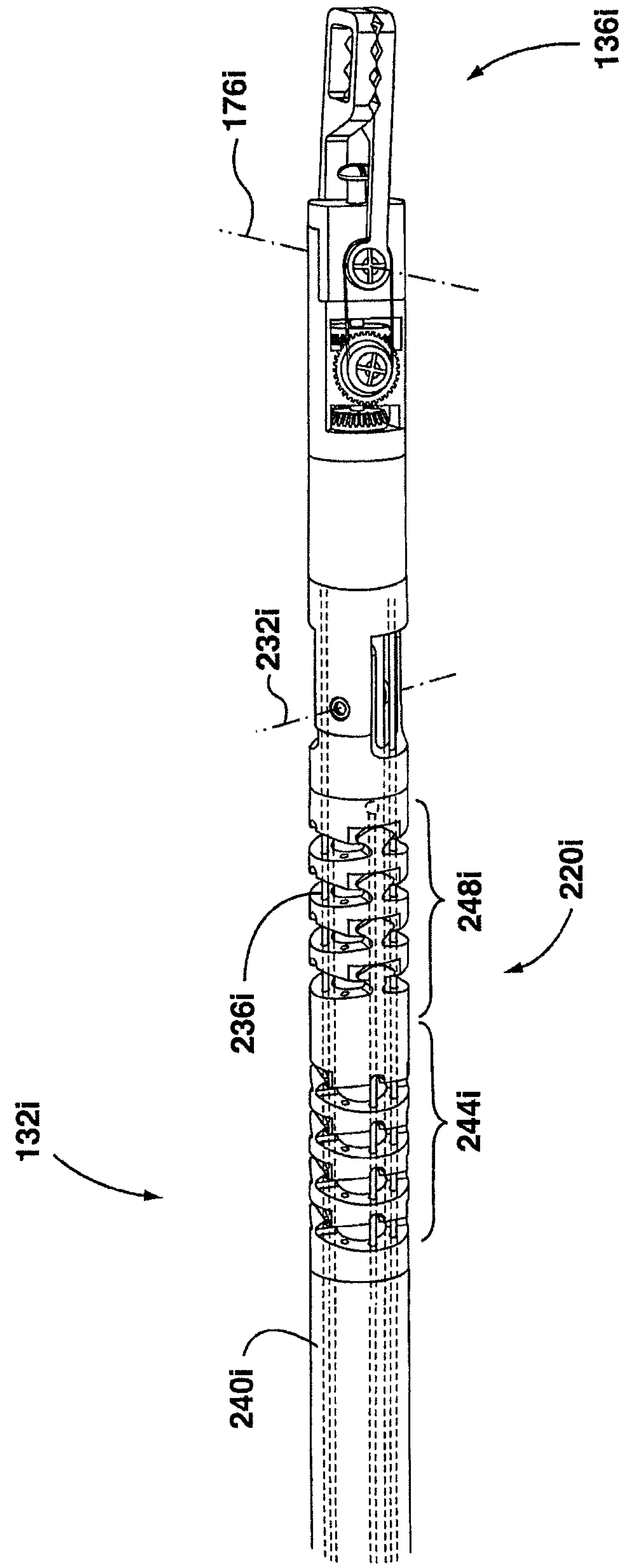


FIG. 25

# APPARATUS AND METHOD FOR CONTROLLING AN END-EFFECTOR ASSEMBLY

## INCORPORATION BY REFERENCE TO ANY PRIORITY APPLICATIONS

Any and all applications for which a foreign or domestic priority claim is identified in the Application Data Sheet as filed with the present application are hereby incorporated by reference under 37 CFR 1.57.

## FIELD

The present specification here relates in general to a field of robotic instruments, and more particularly, to a robotic system for use in surgery.

## BACKGROUND

With the gradual transition of medical surgery from the conventional process of making a long incision in the patient's body for performing a surgery to the next generation of surgery, i.e. minimal invasive surgery (MIS), continuous research is going on to develop and integrate robotic instruments in a system which can be used for MIS purposes. Such integration can help a surgeon perform a surgery in a substantially error-free manner, and at the same time work in a realistic environment that gives the surgeon a feel of conventional surgery.

## SUMMARY

In accordance with an aspect of the invention, there is provided an apparatus for controlling an end-effector assembly. The apparatus includes a first elongated element having a first end and a second end. The first end of the first elongated element is configured to engage the end-effector assembly. The second end of the first elongated element is configured to engage a drive assembly. The apparatus further includes a first motion transfer mechanism disposed at the first end of the first elongated element. The first motion transfer mechanism is configured to transfer a rotational motion of the first elongated element to a first motion of the end-effector assembly. Furthermore, the apparatus includes a second motion transfer mechanism disposed at the second end of the first elongated element. The second motion transfer mechanism is configured to transfer a first motion of the drive assembly to the rotational motion of the first elongated element.

The apparatus may further include a second elongated element having first and second ends. The first end of the second elongated element may be configured to engage the end-effector assembly. The second end of the second elongated element may be configured to engage the drive assembly.

The second elongated element may be configured to adjust a roll of the end-effector assembly.

The apparatus may further include a third motion transfer mechanism disposed at the first end of the second elongated element. The third motion transfer mechanism may be configured to transfer a rotational motion of the second elongated element to a second motion of the end-effector assembly. The apparatus may also include a fourth motion transfer mechanism disposed at the second end of the second elongated element. The fourth motion transfer mechanism may be configured to transfer a second motion of the drive assembly to the rotational motion of the second elongated element.

The first elongated element may include a first tube.

The second elongated element may include a second tube.

The first elongated element may be nested within the second tube.

The first elongated element may be configured to rotate independently from the second tube.

The first motion transfer mechanism of the first elongated element may include a plurality of teeth.

The plurality of teeth of the first elongated element may be configured to mate with a first plurality of teeth of the end-effector assembly.

The third motion transfer mechanism of the second elongated element may include a plurality of teeth.

The plurality of teeth of the second elongated element may be configured to mate with a second plurality of teeth of the end-effector assembly.

The first elongated element may include a flexible portion.

The first elongated element may include stainless steel.

The flexible portion of the first elongated element may be laser cut to increase flexibility.

The second elongated element may include a flexible portion.

The second elongated element may include stainless steel.

The flexible portion of the second elongated element may be laser cut to increase flexibility.

The apparatus may further include a third elongated element having first and second ends. The first end of the third elongated element may be configured to engage the end effector assembly. The second end of the third elongated element may be configured to engage the drive assembly.

The third elongated element may be configured to adjust a roll of the end-effector assembly.

The third elongated element may include a third tube.

The first and second elongated elements may be nested within the third tube.

The first elongated element may be configured to rotate independently from the third tube.

The apparatus may be configured to provide a coarse motion proximate to the end-effector assembly.

The apparatus may further include a plurality of cables to control the coarse motion.

The apparatus may further include a rigid outer cover.

The rigid outer cover may be fixed.

The plurality of cables may be disposed between the rigid outer cover and the first elongated element.

The apparatus may further include an electrical wire extending through the first tube.

At least one elongated element may be electrically conductive.

In accordance with another aspect of the invention, there is an end-effector assembly. The assembly includes a first working member configured to engage a first elongated element. Furthermore, the assembly includes a motion transfer mechanism disposed on the first working member. The motion transfer mechanism is configured to transfer a rotational motion of the first elongated element to a motion of the first working member.

The assembly may further include a connector. The connector may be configured to connect to a second elongated element. The second elongated element may provide a rotational motion to adjust a roll of the end-effector assembly.

The assembly may further include a second working member configured to engage a second elongated element. In addition, the assembly may further include a motion transfer mechanism disposed on the second working member. The motion transfer mechanism mat be configured to transfer a rotational motion of the second elongated element to a motion of the second working member.

The motion transfer mechanism of the first working member may include a plurality of teeth.

The plurality of teeth of the first working member may be configured to mate with a plurality of teeth of the first elongated element.

The motion transfer mechanism of the second working member may include a plurality of teeth.

The plurality of teeth of the second working member may be configured to mate with a plurality of teeth of the second elongated element.

The first working member may include a first jaw.

The motion of the first working member may include opening and closing the first jaw.

The second working member may include a second jaw.

The motion of the second working member may include opening and closing the second jaw.

In accordance with another aspect of the invention, there is provided a drive assembly configured to connect to a rotatable elongated element. The drive assembly includes a drive mechanism configured to engage the rotatable elongated element. Furthermore, the drive assembly includes a motion transfer mechanism disposed on the drive mechanism. The motion transfer mechanism is configured to transfer a motion of the drive mechanism to a rotational motion of the rotatable elongated element.

The motion transfer mechanism may include a plurality of teeth.

The plurality of teeth may be configured to mate with a plurality of teeth of the rotatable elongated element.

The drive mechanism may include an electric motor.

In accordance with another aspect of the invention, there is provided a robotic instrument having first and second ends. The robotic instrument includes an end-effector assembly disposed at the first end of the robotic instrument, the end-effector assembly comprising a first working member. Furthermore, the robotic instrument includes a drive assembly disposed at the second end of the robotic instrument. In addition, the robotic instrument includes a first elongated element having a first end and a second end, the first end of the first elongated element engaged with the end-effector assembly and the second end of the first elongated element engaged with a drive assembly such that rotation of the first elongated element causes the first working member of the end-effector assembly to move.

The robotic instrument may further include a second elongated element having first and second ends. The first end of the second elongated element may be engaged with the end-effector assembly. The second end of the second elongated element may be engaged with the drive assembly.

Rotation of the second elongated element may adjust a roll of the end-effector assembly.

The end-effector assembly may further include a second working member. Rotation of the second elongated element may cause the second working member of the end-effector assembly to move.

The first elongated element may include a first tube.

The second elongated element may include a second tube.

The first elongated element may be nested within the second tube.

The first elongated element may be connected to the end-effector assembly with a gear mechanism.

The second elongated element may be connected to the end-effector assembly with a gear mechanism.

The first elongated element may include a flexible portion.

The first elongated element may include stainless steel.

The flexible portion of the first elongated element may be laser cut to increase flexibility.

The second elongated element may include a flexible portion.

The second elongated element may include stainless steel.

The flexible portion of the second elongated element may be laser cut to increase flexibility.

The robotic instrument may further include a third elongated element having first and second ends. The first end of the third elongated element may be configured to engage the end-effector assembly. The second end of the third elongated element may be configured to engage the drive assembly.

The third elongated element may be configured to adjust a roll of the end-effector assembly.

The third elongated element may include a third tube.

The first and second elongated elements may be nested within the third tube.

The robotic instrument may be configured to provide a coarse motion proximate to the end-effector assembly.

The robotic instrument may further include a plurality of cables to control the coarse motion.

The robotic instrument may further include a rigid outer cover.

The rigid outer cover may be fixed.

The plurality of cables may be disposed between the rigid outer cover and the first elongated element.

The robotic instrument may further include an electrical wire extending through the first tube.

At least one elongated element may be electrically conductive.

The robotic instrument may further include a fixed outer cover.

In accordance with an aspect of the invention, there is provided a method for controlling an end-effector assembly at the end of a robotic instrument. The method involves rotating a first elongated element using a drive assembly, wherein the first elongated element is engaged with the drive assembly. The method further involves transferring a rotational motion of the first elongated element to move a first working member of the end-effector assembly.

The method may further involve rotating a second elongated element using the drive assembly. The second elongated element may be engaged with the drive assembly.

Rotating the second elongated element may adjust a roll of the end-effector assembly.

Rotating the second elongated element may move a second working member of the end-effector assembly.

Rotating a first elongated element may involve rotating a first tube.

Rotating a second elongated element may involve rotating a second tube.

The first elongated element may be nested within the second tube.

The method may further involve flexing a flexible portion of the first elongated element.

The first elongated element may include stainless steel.

The flexible portion of the first elongated element may be laser cut to increase flexibility.

The method may further involve flexing a flexible portion of the second elongated element.

The second elongated element may include stainless steel.

The flexible portion of the second elongated element may be laser cut to increase flexibility.

The method may further involve rotating a third elongated element using the drive assembly. The third elongated element may be engaged with the drive assembly and wherein rotating the third elongated element adjusts a roll of the end-effector assembly.

The third elongated element may include a third tube.

The first and second elongated elements may be nested within the third tube.

The method may further involve controlling a coarse motion of the first end of the first elongated element.

Controlling may involve applying tension to a plurality of cables.

## BRIEF DESCRIPTION OF THE DRAWINGS

Reference will now be made, by way of example only, to the accompanying drawings in which:

FIG. **1** is a perspective view of an operating theater according to an embodiment;

FIG. **2** is a perspective view of a robotic instrument in accordance with an embodiment;

FIG. **3** is another perspective view of the robotic instrument with the working member in an open position in accordance with the embodiment of FIG. **2**;

FIG. **4** is perspective view of a drive assembly of the robotic instrument in accordance with the embodiment of FIG. **2**;

FIG. **5** is a perspective view of a robotic instrument in accordance with another embodiment;

FIG. **6** is another perspective view of the robotic instrument in accordance with the embodiment of FIG. **5** with a cutaway portion;

FIG. **7** is a cross sectional view of a robotic instrument in accordance with the embodiment of FIG. **5** through the line A-A;

FIG. **8** is perspective view of a drive assembly of the robotic instrument in accordance with the embodiment of FIG. **5**;

FIG. **9** is a view showing the a movement of the robotic instrument of FIG. **5**;

FIG. **10** is a perspective view of a robotic instrument in accordance with another embodiment;

FIG. **11** is another perspective view of the robotic instrument in accordance with the embodiment of FIG. **10**;

FIG. **12** is a perspective view of a robotic instrument in accordance with another embodiment;

FIG. **13** is another perspective view of the robotic instrument in accordance with the embodiment of FIG. **12** with a cutaway portion;

FIG. **14** is a cross sectional view of a robotic instrument in accordance with the embodiment of FIG. **12** through the line B-**8**;

FIG. **15** is perspective view of a drive assembly of the robotic instrument in accordance with the embodiment of FIG. **12**;

FIG. **16** is a view showing the a movement of the robotic instrument of FIG. **12**;

FIG. **17** is a perspective view of a robotic instrument in accordance with another embodiment;

FIG. **18** is another perspective view of the robotic instrument in accordance with the embodiment of FIG. **17** with a cutaway portion;

FIG. **19** is a perspective view of a robotic instrument in accordance with another embodiment;

FIG. **20** is a perspective view showing the a movement of a robotic instrument in accordance with another embodiment;

FIG. **21** is a perspective view showing the another movement of a robotic instrument in accordance with the embodiment of FIG. **20**;

FIG. **22** is a perspective view showing the a movement of a robotic instrument in accordance with another embodiment;

FIG. **23** is a perspective view showing the another movement of a robotic instrument in accordance with the embodiment of FIG. **22**;

FIG. **24** is a perspective view of a robotic instrument in accordance with another embodiment; and

FIG. **25** is a perspective view of a portion of a robotic instrument in accordance with another embodiment.

## DETAILED DESCRIPTION OF THE EMBODIMENTS

Referring to FIG. **1**, a schematic representation of an operating theater for Minimal Invasive Surgery (MIS) is shown at **100**. It is to be understood that the operating theater **100** is purely exemplary and it will be apparent to those skilled in the art that a variety of operating theaters are contemplated. The operating theater **100** includes a surgical table **104** and a surgical system **108**. The surgical table **104** includes a surface **112** supported by a base **116**. It is to be understood that the surgical table **104** is not particularly limited to any particular structural configuration. A patient P rests on the surface **112**. The surgical system **108** includes a base unit **120**, an input device **124**, a robotic arm **128**, and at least one robotic instrument **132** with an end-effector assembly **136**.

In a present embodiment, the base unit **120** is generally configured to support and control the robotic arm **128** in response to input control signals from input device **124** under the control of a surgeon or other medical professional. In terms of providing physical support, the base unit **120** is mechanically structured to support the robotic arm **128**, the robotic instrument **132**, and their associated movements. For example, the base unit **120** can be bolted to a fixed structure such as a wall, floor, or ceiling. Alternatively, the base unit **120** can have a mass and a geometry such that when base unit **120** is free-standing, it will support the robotic arm **128**. In some embodiments, the base unit **120** can include a moveable cart to provide easy movement of the base unit **120** around the operating theater **100**. In terms of providing control, the base unit **120** can include mechanical controls (not shown), or electrical controls (not shown), or both. For example, mechanical controls can include gears, cables or other motion transfer mechanisms (not shown) connected to a motor. Other mechanical controls can also involve hydraulics. Alternatively, in embodiments where a motor is disposed in the robotic arm **128** or the robotic instrument **132**, the base unit **120** can supply only electrical control signals to operate the motors in the robotic arm **128** or the robotic instrument **132**.

Referring again to FIG. **1**, the robotic arm **128** is generally configured to support the robotic instrument **132**. In terms of providing physical support, the robotic arm **128** is mechanically structured to support the robotic instrument **132**, and its associated movement. For example, the robotic arm **128** is constructed such that it is rigid enough to be suspended above the patient P. In addition, the robotic arm **128** can be configured so that robotic instrument **132** is positionable in relation to the base unit **120** and surface **112**. For example, the robotic arm **128** can include a moveable joint (not shown) for providing a pivotal degree of freedom. In another example, the robotic arm **128** can include a rail system (not shown) for linear movement of the robotic instrument **132**. It will now be understood that the movement of the robotic arm **128** is controlled by the base unit **120** through various controls described above.

In general terms, the robotic instrument **132** and its end-effector assembly **136** are generally configured for performing MIS responsive to inputs from the input device **124** mediated by the base unit **120** and the robotic arm **128**. However, it is to be re-emphasized that the structure shown in FIG. **1** is a schematic, non-limiting representation only. For example, although only one robotic arm **128** is shown in FIG. **1**, it is to be understood that the surgical system **108** can be modified to include a plurality of robotic arms **128**, each robotic arm **128** having its own a separate robotic instrument **132** and separate end-effector assembly **136**. Furthermore, it is also to be understood that where the surgical system **108** includes a plurality of robotic arms **128** with robotic instruments **132**, each robotic arm **128** or robotic instrument **132** can have different structures. Indeed, a plurality of different configurations of robotic instrument **132** are contemplated herein.

In use, the robotic instrument **132** is configured to provide the end-effector assembly **136** with at least one degree of freedom. A degree of freedom refers to an ability of an end effector assembly **136** to move according to a specific motion. For example, a degree of freedom can include a rotation of the end-effector assembly **136** or a component thereof about a single axis. Therefore, for each axis of rotation, the end-effector assembly **136** is said to have a unique degree of freedom. Another example of a degree of freedom can include a translational movement along a path. It will now be apparent that each additional degree of freedom increases the versatility of the end-effector assembly **136**. By providing more degrees of freedom, it will be possible to position the end-effector assembly **136** in a wider variety of positions or locations to, for example, reach around obstacles.

Referring to FIG. **2**, an embodiment of the robotic instrument **132** is shown in greater detail. It is to be understood that the robotic instrument **132** is purely exemplary and it will be apparent to those skilled in the art that a variety of robotic instruments are contemplated including other embodiments discussed in greater detail below. The robotic instrument **132** includes an end-effector assembly **136**, an elongated element **140** and a drive assembly **144**.

In the present embodiment, the end-effector assembly **136** is shown in FIG. **3**. The end-effector assembly **136** is generally configured to interact with the patient P during MIS. The end-effector assembly **136** includes two working members **148** and **152**. The end-effector assembly **136** also includes a motion transfer mechanism. In the present embodiment, the transfer mechanism is a gear **156** having a plurality of teeth. In particular, the gear **156** of the present embodiment is a bevel gear. However, other embodiments may use other types of gears. It is to be understood that the end-effector assembly **136**, including the working members **148** and **152**, is not particularly limited to any material and that several different types of materials are contemplated. The end-effector assembly **136** is typically constructed from materials which can withstand the harsh conditions of a sterilization process carried out prior to an actual surgery. Some examples of suitable materials include stainless steel, such as surgical stainless steel, titanium, plastics, composites and other materials commonly used in surgical instruments. The exact configuration of working members **148** and **152** is not particularly limited. In the present embodiment shown in FIGS. **2-4**, the working members **148** and **152** are the jaws of forceps. In other embodiments, the working members can be other surgical instruments such as scissors, blades, graspers, clip appliers, staplers, retractors, clamps or bipolar cauterizers or combinations thereof. Also, in other embodiments the end-effector assembly may include a single working member such as imaging equipment, such as a camera or light source, or surgical instruments such as scalpels, hooks, needles, catheters, spatulas or mono-polar cauterizers.

Referring again to FIG. **2**, the elongated element **140** extends between the end effector assembly **136** and the drive assembly **144**. The elongated element **140** is generally configured to support and control the end-effector assembly **136**. It is to be understood that the elongated element **140** is not particularly limited to any material and that several different types of surgical-grade materials are contemplated. Examples of surgical grade materials include surgical stainless steel, titanium, plastics, composites and other materials commonly used in surgery, which in general can withstand sterilization. The elongated element **140** includes two motion transfer mechanisms. In the present embodiment, the motion transfer mechanisms include first and second gears **160** and **164** (FIG. **4**) each having a plurality of teeth and disposed at opposite ends of the elongated element **140**. The first gear **160** is configured to mate with the gear **156** of the end-effector assembly **136**. In certain embodiments, the elongated element **140** is rigid, such that applying a rotational torque about an axis **168** at the second gear **164** will cause the elongated element **140** to rotate without significant deformation at the first gear **160**. It will now be appreciated that the first gear **160** is configured to transfer rotational motion of the elongated element **140** to the gear **156** of the end-effector assembly **136** to move the working member **148**.

The drive assembly **144** of the present embodiment is shown in greater detail in FIG. **4**. The drive assembly **144** includes a motion transfer mechanism. In the present embodiment, the transfer mechanism is a drive gear **172** having a plurality of teeth. The drive gear **172** is configured to mate with the second gear **164** of the elongated element **140**. It will now be appreciated that the drive gear **172** is configured to transfer motion from the drive assembly **144** to a rotational motion of the elongated element **140** about the axis **168** by applying a rotational torque to the second gear **164** of the elongated element **140**. The drive gear **172** can be driven by various means, such as via an electric motor (not shown), hydraulics, pneumatics, magnetic actuators or a piezoelectric motor. It will now be appreciated that the motion used to rotate the drive gear **172** does not need to be a rotational motion and can be any type of motion capable of applying a torque to rotate the drive gear **172**.

In operation, the present embodiment of the robotic instrument **132** controls the movement of the working member **148** of the end-effector assembly **136**. A source of motion in the drive assembly rotates the drive gear **172**. The drive gear **172** engages the second gear **164** of the elongated element **140**. Therefore, as the drive gear **172** is rotated, engagement to second gear **164** of the elongated element **140** will cause the elongated element to rotate about the axis **168**. The rotation of the elongated element **140** will cause a corresponding rotation of the first gear **160**. The first gear **160** engages the gear **156** of the end-effector assembly **136**. Therefore, as the first gear **160** rotates, engagement to the gear **156** of the end-effector assembly **136** will cause the working member **148** to pivot about a first axis **176** to open and close the jaw. It will now be appreciated by a person skilled in the art with the benefit of this description and the accompanying drawings that the working member **152** can be fixed or can also be pivoted about the first axis **176**. When the working member **152** is controlled by the elongated element **140**, rotating the elongated element **140** can cause the working members **148** and **152** to open or close. For example, if the first gear **160** engages both working members **148** and **152** on opposite sides of the first gear **160**, the first gear **160** can apply opposite torques to working members **148** and **152** about the first axis **176**. By applying opposite torques, the working members **148** and **152** may be opened and closed by rotating the elongated element **140**. It is to be understood that when both working members **148** and **152** are controlled by the elongated element **140**, the working members **148** and **152** will close at the same position relative to the elongated element **140**.

Therefore, in embodiments of end-effector assemblies comprising at least one jaw, such as the present embodiment, the first motion is characterized by the rotation motion within the same plane in which a jaw opens and closes.

It will now be appreciated that the first rotational motion provides a degree of freedom which involves rotating the end-effector assembly **136** about a first axis **176**. However, it will now be appreciated that the first axis **176** will be substantially perpendicular to the axis **168** nearest to the first axis **176**. In other words, the first axis **176** is not necessarily fixed with respect to the surface **112** or the surgical system **108**.

In general terms, the robotic instrument **132** is generally configured to transfer a motion from a source in the drive assembly **144** to control the working member **148** of the end effector assembly **136**. It is to be re-emphasized that the structure shown in FIGS. **2** to **4** is a non-limiting representation only. Notwithstanding the specific example, it is to be understood that other mechanically equivalent structures and motion transfer mechanisms can be devised to perform the same function as the robotic instrument **132**. For example, other motion transfer mechanisms can include frictional engagement, belts, or cables or combinations thereof. Furthermore, although the motion of the drive gear **172** is a rotational motion, it is not necessary that this be a rotational motion as discussed above. Other types of motion, such as a linear motion, are also contemplated. Furthermore, in some embodiments, the drive gear **172** and the second gear **164** of the elongated element **140** may be omitted and the elongated element **140** may be directly driven by a motor.

Referring to FIGS. **5** to **9**, another embodiment of a robotic instrument **132***a* is shown. Like components of the robotic instrument **132***a* bear like reference to their counterparts in the robotic instrument **132**, except followed by the suffix “a”. The robotic instrument **132***a* includes an end-effector assembly **136***a*, first and second elongated elements **140***a* and **180***a* respectively, and a drive assembly **144***a*.

In the present embodiment, the end-effector assembly **136***a* is shown in greater detail in FIG. **6**. The end-effector assembly **136***a* is generally configured to interact with the patient P during MIS. The end-effector assembly **136***a* includes two working members **148***a* and **152***a*. The end-effector assembly **136***a* also includes two motion transfer mechanisms. In the present embodiment, the transfer mechanisms are first and second gears **156***a* and **184***a* each having a plurality of teeth. It is to be understood that the end-effector assembly **136***a*, including the working members **148***a* and **152***a*, is not particularly limited to any material and that several different types of materials are contemplated such as those contemplated for the end-effector assembly **136**. The exact configuration of working members **148***a* and **152***a* is not particularly limited. In the present embodiment shown in FIGS. **5** to **9**, the working members **148***a* and **152***a* are jaws of forceps. In other embodiments, the working members can be other surgical instruments such as scissors, blades, graspers, clip appliers, staplers, retractors, clamps or bi-polar cauterizers or combinations thereof. Also, in other embodiments the end effector assembly may include a single working member such as imaging equipment, such as a camera or light source, or surgical instruments such as scalpels, hooks, needles, catheters, spatulas or mono-polar cauterizers.

Referring to FIG. **5**, the first and second elongated elements **140***a* and **180***a* extend between the end-effector assembly **136***a* and the drive assembly **144***a*. The first and second elongated elements **140***a* and **180***a* are generally configured to support and control the end-effector assembly **136***a*. It is to be understood that the first and second elongated elements **140***a* and **180***a* are not particularly limited to any one type material and that several different types of surgical-grade materials are contemplated such as those contemplated for the elongated element **140**. The first and second elongated elements **140***a* and **180***a* each include two motion transfer mechanisms. In the present embodiment, the motion transfer mechanisms of the first elongated element **140***a* include first and second gears **160***a* and **164***a* each having a plurality of teeth and disposed at opposite ends of the elongated element **140***a*. The first gear **160***a* is configured to mate with the first gear **156***a* of the end-effector assembly **136***a*. The motion transfer mechanisms of the second elongated element **180***a* include first and second gears **188***a* and **192***a* each having a plurality of teeth and each disposed at opposite ends of the second elongated element **180***a*. The first gear **188***a* is configured to mate with the second gear **184***a* of the end-effector assembly **136***a*. In certain embodiments, the first and second elongated elements **140***a* and **180***a* are each rigid, such that independently applying a rotational torque about an axis **168***a* at the second gears **164***a* and **192***a* will cause the first and second elongated elements **140***a* and **180***a*, respectively, to rotate independently from each other without significant deformation. It will now be appreciated that the first gears **160***a* and **188***a* are configured to transfer rotational motion of the first and second elongated elements **140***a* and **180***a* to the first and second gears **156***a* and **184***a* of the end-effector assembly **136***a* to move, independently, the working members **148***a* and **152***a*, respectively.

Referring to FIG. **6**, the first gears **160***a* and **188***a* of the present embodiment are sector gears. Using sector gears in the present embodiment permits both of the first gears **160***a* anti **188***a* to rotate within a range of angles in the same plane to independently control the working members **148***a* and **152***a*. It is to be understood that the first gears **160***a* and **188***a* are not limited to sector gears and that other other embodiments are contemplated. For example, the first gears **160***a* and **188***a* can be modified to be other types of gears such as nested circular gear racks.

Referring to FIG. **8**, the drive assembly **144***a* of the present embodiment is shown in greater detail in FIG. **8**. The drive assembly **144** includes two motion transfer mechanisms. In the present embodiment, the transfer mechanisms are first and second drive gears **172***a* and **196***a*, each having a plurality of teeth. The first and second drive gears **172***a* and **196***a* are configured to mate with the gears **164***a* and **192***a* respectively. It will now be appreciated that the first and second drive gears **172***a* and **196***a* are configured to transfer, independently, motion from the drive assembly **144***a* to a rotational motion of the first and second elongated elements **140***a* and **180***a* about the axis **168***a*, respectively, by applying a rotational torque to the second gears **164***a* and **192***a*, respectively. The first and second drive gears **172***a* and **196***a* can be driven, independently, by various means, such as those discussed above in connection with drive assembly **144**.

In operation, the present embodiment of the robotic instrument **132***a* controls the movement of the working members **148***a* and **152***a* of the end-effector assembly **136***a*. A source of motion in the drive assembly rotates the first and second drive gears **172***a* and **196***a*. The first and second drive gears **172***a* and **196***a* engage the second gears **164***a* and **192***a* of the elongated elements **140***a* and **180***a*, respectively. Therefore, as the drive gear **172***a* is rotated, engagement to second gear **164***a* of the first elongated element **140***a* will cause the first elongated element to rotate about the axis **168***a*. The rotation of the first elongated element **140***a* will cause a corresponding rotation of the first gear **160***a*. The first gear **160***a* engages the first gear **156***a* of the end-effector assembly **136***a*. Therefore, as the first gear **160***a* rotates, engagement to the first gear **156***a* of the end-effector assembly **136***a* will cause the working member **148***a* to pivot about a first axis **176***a*. Similarly, as the drive gear **196***a* is rotated, engagement to second gear **192***a* of the second elongated element **180***a* will cause the second elongated element to rotate about the axis **168***a*. The rotation of the second elongated element **180***a* will cause a corresponding rotation of the first gear **188***a*. The first gear **188***a* engages the second gear **184***a* of the end-effector assembly **136***a*. Therefore, as the first gear **188***a* rotates, engagement to the second gear **184***a* of the end-effector assembly **136***a* will cause the working member **152***a* to pivot about the first axis **176***a*.

It will now be appreciated by a person skilled in the art with the benefit of this description and the accompanying drawings that, in the present embodiment, the working members **148***a* and **152***a* can be pivoted about the first axis **176***a* independently to open and close the jaw.

It will now be appreciated that the independent control of the working members **148***a* and **152***a* provides an addition degree of freedom over the robotic instrument **132** which involves rotating the working members **148***a* and **152***a* about the first axis **176***a* as shown in FIG. **9**. Therefore, the independent control of the working members **148***a* and **152***a* allows the working members to open and close over a range of angles about the first axis **176***a*, whereas the working members **148** and **152** were only able to open can close at a fixed angle.

Variations are contemplated. For example, although the present embodiment shows the first and second elongated elements **140***a* and **180***a* are nested tubes, it is to be understood that the embodiment is purely exemplary and it will be apparent to those skilled in the art that a variety of different configurations of the first and second elongated elements **140***a* and **180***a* are contemplated. For example, the first elongated element **140***a* can be modified such that it is not a hollow tube. Furthermore, it is also contemplated that the second elongated element **180***a* can be modified into a solid rod in some embodiments. In other embodiments, the first and second elongated elements **140***a* and **180***a*, respectively, can be modified such that they are not nested and instead are parallel and adjacent.

Referring to FIGS. **10** and **11**, another embodiment of a robotic instrument **132***b* is shown Like components of the robotic instrument **132***b* bear like reference to their counterparts in the robotic instruments **132** and **132***a*, except followed by the suffix "b". The robotic instrument **132***b* includes an end-effector assembly **136***b*, first and second elongated elements **140***b* and **180***b* respectively, and a drive assembly (not shown).

The end-effector assembly **136***b* is generally configured to interact with the patient P during MIS. The end-effector assembly **136***b* includes two working members **148***b* and **152***b*. The end-effector assembly **136***b* also includes two motion transfer mechanisms. In the present embodiment, the motion transfer mechanisms of the end-effector assembly **136***b* include a first rotating element **157***b* and a second rotating element **185***b*. A first gear **156***b* and a second gear **184***b*, each gear having a plurality of teeth, are disposed on the first and second rotating elements **157***b* and **185***b*, respectively. In the present embodiment, the motion transfer mechanisms further include a first end-effector cable **158***b* and a second end-effector cable **186***b* which are engaged with first and second rotating elements **157***b* and **185***b* (coupled to the first and second gears **156***b* and **184***b*, respectively) and the first and second working members **148***b* and **152***b* as shown in FIG. **11**. In the present embodiment, the first end-effector cable **158***b* and a second end-effector cable **186***b* are cables suitable for surgical applications. In other embodiments, the first and second end-effector cables **158***b* and **186***b* can be modified to be a belt or chain. The end-effector assembly **136***b* also includes a set screw **149***b* configured to adjust the tension of the first and second end-effector cables **158***b* and **186***b*. Therefore, as the first and second end-effector cables **158***b* and **186***b* wear and expand over time, the set screw can be adjusted to maintain the required tension in the motion transfer mechanisms.

Referring to FIG. **10**, the first and second elongated elements **140***b* and **180***b* extend between the end-effector assembly **136***b* and the drive assembly (not shown). The first and second elongated elements **140***b* and **180***b* are generally configured to support and control the end-effector assembly **136***b*. The first and second elongated elements **140***b* and **180***b* each include a motion transfer mechanism. In the present embodiment, the motion transfer mechanism of the first elongated element **140***b* includes a gear **160***b* having a plurality of teeth disposed thereon. The gear **160***b* is configured to mate with the first gear **156***b* on the first rotatable element **157***b* of the end-effector assembly **136***b*. The motion transfer mechanism of the second elongated element **180***b* includes a gear **188***b* having a plurality of teeth **180***b* disposed thereon. The gear **188***b* is configured to mate with the second gear **184***b* on the second rotatable element **185***b* of the end-effector assembly **136***b*. It will now be appreciated that the gears **160***b* and **188***b* are configured to transfer rotational motion of the first and second elongated elements **140***b* and **180***b* to the first and second gears **156***b* and **184***b* to move, independently, the first and second rotatable elements **157***b* and **185***b*, respectively. In turn the first and second rotatable elements **157***b* and **185***b* apply tension to the first and second end effector cables **158***b* and **185***b* to move the working members **148***b* and **152***b*, respectively.

It will now be appreciated by a person skilled in the art with the benefit of this description and the accompanying drawings that, in the present embodiment, the working members **148***b* and **152***b* can be pivoted about the first axis **176***b* (shown in FIG. **11**) independently to open and close the jaw. Furthermore, it will also now be appreciated that by using first and second rotatable elements **157***b* and **185***b* in combination with the first and second end-effector cables **158***b* and **186***b*, the range of motion of the first and second working members **148***b* and **152***b* is increased compared with the embodiment shown in FIG. **6** where the gears **160***a* and **188***a* are sector gears.

Referring to FIGS. **12** to **16**, another embodiment of a robotic instrument **132***c* is shown. Like components of the robotic instrument **132***c* bear like reference to their counterparts in the robotic arms **132** and **132***a*, except followed by the suffix "c". The robotic instrument **132***c* includes an end-effector assembly **136***c*, first, second, and third elongated elements **140***c*, **180***c*, and **200***c* respectively, and a drive assembly **144***c*.

In the present embodiment, the end-effector assembly **136***c* is shown in greater detail in FIG. **13**. The end-effector assembly **136***c* is generally configured to interact with the patient P during MIS. The end-effector assembly **136***c* includes two working members **148***c* and **152***c*. The end-effector assembly **136***c* also includes two motion transfer mechanisms. In the present embodiment, the transfer mechanisms are first and second gears **156***c* and **184***c* each having a plurality of teeth. It is to be understood that the end-effector assembly **136***c*, including the working members **148***c* and **152***c*, is not particularly limited to any material and that several different types of materials are contemplated such as those contemplated for the end-effector assemblies **136** and **136***a*. The exact configuration of working members **148***c* and **152***c* is not particularly limited. In the present embodiment shown in FIGS. **12** to **16**, the working members **148***c* and **152***c* are jaws of forceps.

Referring to FIGS. **12** and **13**, the first, second, and third elongated elements **140***c*, 1 BOc, and **200***c* extend between the end-effector assembly **136***c* and the drive assembly **144***c*. The first, second, and third elongated elements **140***c*, **180***c*, and **200***c* are generally configured to support and control the end-effector assembly **136***c*. It is to be understood that the first, second, and third elongated elements **140***c*, **180***c*, and **200***c* are not particularly limited to any one type material and that several different types of surgical-grade materials are contemplated such as those contemplated for the elongated elements **140**, **140***a* and **180***a*. The first and second elongated elements **140***c* and **180***c* each include two motion transfer mechanisms. In the present embodiment, the motion transfer mechanisms of the first elongated element **140***c* include first and second gears **160***c* and **164***c* each having a plurality of teeth and disposed at opposite ends of the elongated element **140***c*. The first gear **160***c* is configured to mate with the first gear **156***c* of the end-effector assembly **136***c*. The motion transfer mechanisms of the second elongated element **180***c* include first and second gears **188***c* and **192***c* each having a plurality of teeth and each disposed at opposite ends of the second elongated element **180***c*. The first gear **188***c* is configured to mate with the second gear **184***c* of the end-effector assembly **136***c*. The third elongated element **200***c* includes a motion transfer mechanism. In the present embodiment, the motion transfer mechanism of the third elongated element **200***c* is a gear **204***c* disposed the end of the third elongated element **200***c* proximate to the drive assembly **144***c*. The opposite end **208***c* of the third elongated element **200***c* is connected to the end-effector assembly **136***c*.

In certain embodiments, the first, second, and third elongated elements **140***c*, **180***c*, and **200***c* are each rigid, such that independently applying a rotational torque about an axis **168***c* at the gears **164***c*, **192***c*, and **204***c* will cause the first, second, and third elongated elements **140***c*, **180***c*, and **200***c*, respectively, to rotate independently from each other without significant deformation. It will now be appreciated that the first gears **160***c* and **188***c* of the first and second elongated elements **140***c* and **180***c* are configured to transfer rotational motion of the first and second elongated elements to the first and second gears **156***c* and **184***c* of the end effector assembly **136***c* to move, independently, the working members **148***c* and **152***c*, all respectively.

Referring to FIG. **15**, the drive assembly **144***c* of the present embodiment is shown in greater detail in FIG. **15**. The drive assembly **144***c* includes three motion transfer mechanisms. In the present embodiment, the transfer mechanisms are first, second, and third drive gears **172***c*, **196***c*, and **212***c* each having a plurality of teeth. The first, second, and third drive gears **172***c*, **196***c*, and **212***c* are configured to mate with the gears **164***c*, **192***c*, and **204***c* respectively. It will now be appreciated that the first, second, and third drive gears **172***c*, **196***c*, and **212***c* are configured to transfer, independently, motion from the drive assembly **144***c* to a rotational motion of the first, second, and third elongated elements **140***c*, **180***c*, and **200***c* about the axis **168***c*, respectively, by applying a rotational torque to the gears **164***c*, **192***c*, and **204***c*, respectively. The first, second, and third drive gears **172***c*, **196***c*, and **212***c* can be driven, independently, by various means, such as those discussed above in connection with drive assemblies **144** and **144***a*.

In operation, the present embodiment of the robotic instrument **132***c* controls the movement of the end-effector assembly **136***c*, which includes the movements of the working members **148***c* and **152***c*. A source of motion in the drive assembly **144***c* rotates the first, second, and third drive gears **172***c*, **196***c*, and **212***c*. The first, second, and third drive gears **172***c*, **196***c*, and **212***c* engage the gears **164***c*, **192***c*, and **204***c* of the first, second and third elongated elements **140***c*, **180***c*, and **200***c* respectively. Therefore, as the drive gear **172***c* is rotated, engagement to second gear **164***c* of the first elongated element **140***c* will cause the first elongated element to rotate about the axis **168***c*. The rotation of the first elongated element **140***c* will cause a corresponding rotation of the first gear **160***c*. The first gear **160***c* engages the first gear **156***c* of the end-effector assembly **136***c*. Therefore, as the first gear **160***c* rotates, engagement to the first gear **156***c* of the end-effector assembly **136***c* will cause the working member **148***c* to pivot about a first axis **176***c*. Similarly, as the drive gear **196***c* is rotated, engagement to second gear **192***c* of the second elongated element **180***c* will cause the second elongated element to rotate about the axis **168***c*. The rotation of the second elongated element **180***c* will cause a corresponding rotation of the first gear **188***c*. The first gear **188***c* engages the second gear **184***c* of the end-effector assembly **136***c*. Therefore, as the first gear **188***c* rotates, engagement to the second gear **184***c* of the end-effector assembly **136***c* will cause the working member **152***c* to pivot about the first axis **176***c*. As the drive gear **212***c* is rotated, engagement to gear **204***c* of the third elongated element **200***c* will cause the third elongated element to rotate about the axis **168***c*. The rotation of the third elongated element **200***c* will cause a corresponding rotation of the end **208***c*. Since the end **208***c* is connected to the end-effector assembly **136***c*, rotation of the third elongated element **200***c* will cause the end-effector assembly **136***c* to rotate about the axis **168***c*. It will now be appreciated by a person skilled in the art with the benefit of this description and the accompanying drawings that, in the present embodiment, the working members **148***c* and **152***c* can be pivoted about the first axis **176***c* independently to open and close the jaw. It will also now be appreciated that since the end-effector assembly **136***c* can be rotated about the axis **168***c*, the first axis **176***c* is not necessarily fixed and can be rotated as well.

Referring to FIG. **16**, it will now be appreciated that the independent rotation of the end-effector assembly **136***c* provides an addition degree of freedom over the robotic instrument **132***a* which involves rotating the working members **148***c* and **152***c* about the axis **168***c* as shown in FIG. **16**, where the axis **168***c* is shown in FIGS. **12**, **14**, and **15**. Therefore, independent control of the third elongated element **200***c* allows the working members **148***c* and **152***c* to reach over all angles about the axis **168***c*. This specific degree of freedom is referred to as a roll motion. It is to be understood that variations are contemplated whereby the axis **168***c* is not straight, such as the embodiment generally shown in FIG. **24**, which will be discussed later as an embodiment where the elongated element can be bent.

Variations are contemplated. For example, although the present embodiment shows the first, second, and third elongated elements **140***c*, **180***c*, and **200***c* are nested tubes, it is to be understood that the embodiment is purely exemplary and it will be apparent to those skilled in the art that a variety of different configurations of the first, second, and third elongated elements **140***c*, **180***c*, and **200***c* are contemplated. In other embodiments, the first, second, and third elongated elements **140***c*, **180***c*, and **200***c*, respectively, can be modified such that they are not nested and instead are parallel and adjacent.

Referring to FIGS. **17** and **18**, another embodiment of a robotic instrument **132***d* is shown Like components of the robotic instrument **132***d* bear like reference to their counterparts in the robotic arms **132**, **132***a* and **132***d*, except followed by the suffix "d". The robotic instrument **132***d* includes an end-effector assembly **136***d*, first and second elongated elements **140***d* and **200***d* respectively, and a drive assembly **144***d*.

In the present embodiment, the end-effector assembly **136***d* is shown in greater detail in FIG. **18**. The end-effector assembly **136***d* is generally configured to interact with the patient P during MIS. The end-effector assembly **136***d* includes a working member **148***d*. The end-effector assembly **136***d* also includes a motion transfer mechanism. In the present embodiment, the transfer mechanism is a gear **156***d* having a plurality of teeth. It is to be understood that the end-effector assembly **136***d*, including the working member **148***d*, is not particularly limited to any material and that several different types of materials are contemplated such as those contemplated for the end-effector assemblies **136**, **136***a*, and **136***c*. The exact configuration of the working member **148***d* is not particularly limited. In the present embodiment shown in FIGS. **17** and **18**, the working member **148***d* is a surgical blade capable of cauterizing.

Referring again to FIGS. **17** and **18**, the first and second elongated elements **140***d* and **200***d* extend between the end-effector assembly **136***d* and the drive assembly **144***d*. The first and second elongated elements **140***d* and **200***d* are generally configured to support and control the end-effector assembly **136***d*. It is to be understood that the first and second elongated elements **140***d* and **200***d* are not particularly limited to any one type material and that several different types of surgical-grade materials are contemplated. The first elongated element **140***d* includes two motion transfer mechanisms. In the present embodiment, the motion transfer mechanisms of the first elongated element **140***d* include first and second gears **160***d* and **164***d* each having a plurality of teeth and disposed at opposite ends of the elongated element **140***d*. The first gear **160***d* is configured to mate with the gear **156***d* of the end-effector assembly **136***d*. The second elongated element **200***d* includes a motion transfer mechanism. In the present embodiment, the motion transfer mechanism of the second elongated element **200***d* is a gear **204***d* disposed the end of the second elongated element **200***d* proximate to the drive assembly **144***d*. The opposite end **208***d* of the second elongated element **200***d* is connected to the end-effector assembly **136***d*.

In the present embodiment, the robotic instrument **132***d* additionally includes an electrical wire **216***d* extending through the first elongated element **140***d* to the working member **148***d*. The electrical wire **216***d* is generally configured to supply an electrical current to the working member **148***d*. The electrical current can be used to generate heat at the working member **148***d* to cauterize tissue when necessary. Although the present embodiment uses the electrical wire **216***d*, the robotic instrument can modified to provide the same functionality without an electrical wire. For example, the first elongated element **140***d* can be made of stainless steel, which is electrically conductive. Therefore, the electrical conductivity of the first elongated element **140***d* can be used in place of the electrical wire **216***d*.

In certain embodiments, the first and second elongated elements **140***d* and **200***d* are each rigid, such that independently applying a rotational torque about an axis **168***d* at the gears **164***d* and **204***d* will cause the first and second elongated elements **140***d* and **200***d*, respectively, to rotate independently from each other without significant deformation. It will now be appreciated that the first gear **160***d* of the first elongated elements **140***d* is configured to transfer rotational motion of the first elongated element **140***d* to the gear **156***d* of the end-effector assembly **136***d* to move the working member **148***d*.

Referring again to FIGS. **17** and **18**, the drive assembly **144***d* includes two motion transfer mechanisms. In the present embodiment, the transfer mechanisms are first and second drive gears **172***d* and **212***d*, each having a plurality of teeth. The first and second drive gears **172***d* and **212***d* are configured to mate with the gears **164***d* and **204***d* respectively. It will now be appreciated that the first and second drive gears **172***a* and **212***d* are configured to transfer, independently, motion from the drive assembly **144***d* to a rotational motion of the first and second elongated elements **140***d* and **200***d* about the axis **168***d*, respectively, by applying a rotational torque to the second gears **164***d* and **204***d*, respectively. The first and second drive gears **172***d* and **212***d* can be driven, independently, by various means, such as those discussed above in connection with drive assemblies **144**, **144***a*, and **144***d*.

In operation, the present embodiment of the robotic instrument **132***d* controls the movement of the end-effector assembly **136***d*, which includes the movements of the working member **148***d*. A source of motion in the drive assembly **144***d* rotates the first and second drive gears **172***d* and **212***d*. The first and second drive gears **172***d* and **212***d* engage the gears **164***d* and **204***d* of the first and second elongated elements **140***d* and **200***d* respectively. Therefore, as the drive gear **172***d* is rotated, engagement to gear **164***d* of the first elongated element **140***d* will cause the first elongated element to rotate about the axis **168***d*. The rotation of the first elongated element **140***d* will cause a corresponding rotation of the first gear **160***d*. The gear **160***d* engages the gear **156***d* of the end-effector assembly **136***d*. Therefore, as the gear **160***d* rotates, engagement to the gear **156***d* of the end-effector assembly **136***d* will cause the working member **148***d* to pivot about a first axis **176***d*. Similarly, as the drive gear **212***d* is rotated, engagement to gear **204***d* of the second elongated element **200***d* will cause the second elongated element to rotate about the axis **168***d*. The rotation of the second elongated element **200***d* will cause a corresponding rotation of the end **208***d*. Since the end **208***d* is connected to the end-effector assembly **136***d*, rotation of the second elongated element **200***d* will cause the end-effector assembly **136***d* to rotate about the axis **168***d*. It will now be appreciated by a person skilled in the art with the benefit of this description and the accompanying drawings that, in the present embodiment, the working member **148***d* can be pivoted about the first axis **176***d* independently from the rotation of the end-effector assembly **136***d*.

Variations are contemplated. For example, although the present embodiment shows a single working member **148***d*, the robotic instrument **132***d* can be modified to include a different number of working members. For example, previous embodiments show variations including two working members. However, the number of working members are not limited to two and a larger number of working members are contemplated.

Referring to FIG. **19**, another embodiment of a robotic instrument **132***e* is shown Like components of the robotic instrument **132***e* bear like reference to their counterparts, except followed by the suffix "e". The robotic instrument **132***e* includes an end-effector assembly **136***e*, first and second elongated elements **140***e* and **180***e* respectively, and a drive assembly (not shown).

Each elongated element **140***e* and **180***e* include a flexible portion disposed generally at **220***e*. The flexible portion allows for coarse motion of the elongated elements **140***e* and **180***e*, which provides even more degrees of freedom to the robotic instrument **132***e*. The flexible portion can be provided by using laser cutting techniques on the first and second elongated elements **140***e* and **180**. The first and second laser cut elongated elements **140***e* and **180** may be obtained from Pulse Systems (Concord, Calif., U.S.A.) using uncut stainless steel tubes from VitaNeedle (Needham, Mass., U.S.A.). By laser cutting a stainless steel tube, it has been found that the flexibility of the stainless steel tube dramatically increases without compromising the rotational rigidity. Therefore, the laser cut stainless steel tubes have been shown to work well for providing flexibility, while still being effective at transferring rotational motion from a drive assembly to the end-effector assembly **136***e*. Although the laser cutting is shown in FIG. **19** to have produced spiral scores **224***e* and **228***e* on the first and second elongated elements **140***e* and **180***e*, respectively, variations are contemplated. It will now be appreciated that different laser cut patterns can have different characteristics and that the cut pattern selected depends on various factors.

It is also contemplated that other ways of providing a flexible portion can be used. For example, the composition of the elongated elements **140***e* and **180***e* can be varied such that a portion of each elongated element **140***e* and **180***e* is more flexible than other portions.

FIGS. **20** and **21** provide view of another exemplary robotic instrument **132***f* and its associated end-effector assembly **136***f*. The robotic instrument **132***f* includes an end-effector assembly **136***f* and an elongated element **140***f*. The end-effector assembly **136***f* is configured for another degree of freedom. The rotational motion shown in FIG. **20** is a degree of freedom which involves rotating the end-effector assembly **136***f* about the second axis **232***f*. In some embodiments, the second axis **232***f* is perpendicular to the first axis **176***f* to provide the robotic instrument **132***f* with the greatest range of motion. However, it is not essential that the second axis **232***f* be perpendicular to the first axis **176***f*. For example, similar to some of the previously discussed embodiments, the first axis **176***f* can be rotatable relative to the second axis **232***f*.

FIG. **21** shows another degree of freedom involving a longitudinal translation motion allowing the robotic instrument **132***f* to be translated along axis **168***f*. For example, this allows the robotic instrument **132***f* to enter and penetrate deeper into the body, or be retracted. Unlike the other degrees of freedom discussed, this translational degree of freedom is provided by a system on the robotic arm **128**. For example, the robotic arm can include a z-rail system (not shown) for moving the entire robotic instrument **132***f*.

FIGS. **22** and **23** provide view of another exemplary robotic instrument **132***g* and its associated end-effector assembly **136***g*. The robotic instrument **132***g* includes an end-effector assembly **136***g* and an elongated element **140***g*. The end-effector assembly **136***g* is configured for another degree of freedom similar to the end-effector assembly **136***f*.

FIG. **23** shows another degree of freedom involving a longitudinal translation motion allowing the robotic instrument **132***g* to be translated along axis **168***g*. For example, this allows the robotic instrument **132***g* to enter and penetrate deeper into the body, or be retracted. For example, the robotic arm can include a z-rail system (not shown) for moving the entire robotic instrument **132***g*.

It is to be understood that degrees of freedom allow for a range of movements for facilitating MIS. Variations are contemplated and additional degrees of freedom not discussed in this application can be added. For example, the robotic instrument **132***f* can be externally moved using the robotic arm **128** or other suitable means. Therefore, the motion of the robotic arm **128** can move the end-effector assembly **136***f* over a large distance as an additional degree of freedom.

Referring to FIG. **24**, another embodiment of a robotic instrument **132***h* is shown Like components of the robotic arm **132***h* bear like reference to their counterparts, except followed by the suffix "h". The robotic instrument **132***h* includes an end-effector assembly **136***h*, first, second, and third elongated elements (not shown) encased in a cover **240***h*, and a drive assembly **144***h*. In this particular embodiment, the robotic instrument **132***h* includes a flexible portion **220***h* configured to provide coarse motion proximate to the end-effector assembly **136***h*. The flexible portion **220***h* is located between the cover **240***h* and the end-effector assembly **136***h*.

The flexible portion **220***h* includes first and second subsections **244***h* and **248***h*. Each of the first and second subsections **244***h* and **248***h* is generally configured to bend within first and second coarse motion planes, respectively. It is to be understood that the first, second, and third elongated elements (not shown} are consequently bent when the first and second subsections **244***h* and **248***h* are bent such that the first, second, and third elongated elements can independently rotate while bent. Furthermore, the motion of the first subsection **244***h* and the second subsection **248***h* are independent such that one or both of the first and second subsections may be bent independently. Therefore, it is to be understood that the coarse motion of the robotic instrument **132***h* can be controlled using a set of at least one course motion adjustment cable **236***h* for each of subsection **244***h* and **248***h* by independently adjusting the tension of each set of at least one course motion adjustment cable.

Referring again to FIG. **24**, in the present embodiment, the first and second coarse motion planes are substantially perpendicular to each other. However, it is to be appreciated that the first and second coarse motion planes do not need to be perpendicular to each other and can be at any angle in some embodiments. Furthermore, the exact configuration of first and second subsections **244***h* and **248***h* is not particularly limited. In the present embodiment, there are two subsections **244***h* and **248***h*. In other embodiments, it is to be understood that the flexible portion **220***h* can be modified to include more subsections to provide more coarse motion planes within which subsections of the flexible portion **220***h* can bend. In addition, the subsections need not be place adjacent to each other. Alternatively, it is also to be understood that the flexible portion **220***h* can be modified to include only one subsection to provide a single coarse motion plane.

In addition, the robotic instrument **132***h* includes an outer cover **240***h*. It is to be appreciated that the outer cover **240***h* can be rigid to provide support for the elongated elements (not shown) within the outer cover. In addition, the plurality of coarse motion adjustment cables **236***h* can be disposed within the outer cover **240***h* in a pace between the inside wall of the outer cover and the elongated elements. By placing the coarse motion adjustment cables **236***h* behind an outer cover, it is to be understood that wear on the cables is reduced. Furthermore, in the embodiment shown in FIG. **24**, the outer cover **240***h* is fixed. That is, the outer cover **240***h* does not rotate. It will now be appreciated that when the robotic instrument **132***t* is inserted inside the patient P, the outer cover **240***h* reduces the chance of the robotic instrument **132***h* getting caught on something to cause damage.

It will now be appreciated that each subsection **244***h* and **248***h* will provide an additional degree of freedom. Referring back to FIG. **24**, it will also now be apparent that the first and second subsections **244***h* and **248***h* add two more degrees of freedom to the robotic instrument **132***h*. Therefore, the robotic instrument **132***h* includes six degrees of freedom. The six degrees of freedom include the roll about the axis **168***h* (where the first, second, and third elongated elements rotate concurrently), rotation of the end-effector assembly **136***h* about a second axis **232***h*, rotation of a first working member **148***h* about a first axis **176***h*, rotation of a second working member **152***h* about the first axis **176***h*, the bending of the first subsection **244***h* and the bending of the second subsection **248***h*. In addition, the entire robotic instrument **132***h* can be moved on a rail system (not shown) to provide a seventh degree of freedom.

It is to be understood that by moving the first and second working members **148***h* and **152***h* together by rotating the first and second elongated elements, the working members **148***h* and **152***h* can rotate together about the first axis **176***h* such that the working members **148***h* and **152***h* can open and close over a range of angles about the first axis **176***h*. Furthermore, it will also be appreciated that to change the angle about the first axis **176***h* at which the working members **148***h* and **152***h* open and close, the first and second elongated elements rotate at a different amount compared with the third elongated element. This different amount is called a delta and can be adjusted to control the movement of the end effector assembly **136***h* relative to the robotic instrument **132***h*.

Referring to FIG. **25**, another embodiment of a robotic instrument **132***i* is shown Like components of the robotic arm **132***i* bear like reference to their counterparts, except followed by the suffix "i". The robotic instrument **132***i* includes an end-effector assembly **136***i*, first, second, and third elongated elements (not shown) encased in a cover **240***i*, and a drive assembly **144***i*. In this particular embodiment, the robotic instrument **132***i* includes a flexible portion **220***i* configured to provide coarse motion proximate to the end-effector assembly **136***i* in a similar manner to the flexible portion **220***h* in the robotic instrument **132***h*. The flexible portion **220***i* is located between the cover **240***i* and the end-effector assembly **136***i*. The end-effector assembly **136***i* is similar to the end-effector assembly **136***b* described. Therefore, the robotic instrument **132***i* shown in FIG. **23** adds coarse motion to the end-effector assembly **136***b*.

Referring again to FIG. **22**, it will now be appreciated that if the roll motion rotates the first axis **176***g* relative to the second axis **232***g*, the robotic instrument **132***g* would have positions where the first axis **176***g* can be parallel to the second axis **2329**. However, in the embodiment shown in FIG. **25**, the roll motion rotates both the first axis **176***i* and the second axis **232***i* by having the rotation occur between the flexible portion **220***i* and the second axis **232***i*. Therefore, the angle between the first axis **176***h* and the second axis **232***i* remains fixed. In the present embodiment, the angle between the first axis **176***i* and the second axis **232***i* is maintained at 90 degrees. However, in other embodiments, the angle can be greater or smaller than 90 degrees.

Therefore, it is to be understood that many combinations, variations and subsets of the embodiments and teachings herein are contemplated. As a non-limiting example, the robotic instrument **132***d* can be modified with the variation described in relation to the robotic instrument **132***g* to provide for coarse motion in the robotic instrument **132***d*. As another nonlimiting example, the robotic instrument **132** can be modified with the variation described in relation to the robotic instrument **132***d* to provide cauterizing functionality to the robotic instrument **132**.

While specific embodiments have been described and illustrated, such embodiments should be considered illustrative only and should not serve to limit the accompanying claims.

What is claimed is:

**1**. A robotic surgical instrument, comprising:

an end-effector assembly comprising a working member configured to pivot about a first axis;

an elongated element extending between a proximal end and a distal end, the distal end being affixed with respect to the end effector assembly to hold the first axis perpendicular to the elongated element;

a second elongated element extending between a second proximal end and a second distal end, the second distal end of the second elongated element being coupled with the end effector assembly so that rotation of the second elongated element about a second axis pivots the working member about the first axis; and

a drive assembly comprising a first drive member coupled to the proximal end of the elongated element and a second drive member coupled to the second proximal end of the second elongated element, the drive assembly configured to selectively operate the first drive member to rotate the elongated element and configured to selectively operate the second drive member to rotate the second elongated element,

wherein the elongated element and second elongated element are nested together, and wherein the elongated element is a first tube, the second elongated element is a second tube, and the elongated element and second elongated element are nested together so that one of the first tube and the second tube is disposed within the other of the first tube and the second tube.

**2**. The robotic surgical instrument of claim **1**, wherein the working member is a blade.

**3**. The robotic surgical instrument of claim **1**, wherein the working member is configured to cauterize a tissue.

**4**. The robotic surgical instrument of claim **1**, wherein one or both of the elongate member and the second elongate member comprises a flexible portion.

**5**. The robotic surgical instrument of claim **1**, wherein one or both of the first and second drive members comprise a gear.

**6**. The robotic surgical instrument of claim **1**, wherein one or both of the first and second drive members rotate about a third axis offset from the second axis.

**7**. The robotic surgical instrument of claim **1**, further comprising an electrical wire extending through the second elongated element and coupled to the working member.

**8**. The robotic surgical instrument of claim **1**, wherein the second distal end of the second elongated element is coupled to the working member of the end-effector assembly via a gear.

**9**. A robotic surgical system, comprising:

a support arm; and

a surgical instrument coupled to the support arm, the surgical instrument comprising:

an end-effector assembly comprising a working member configured to pivot about a first axis,

an elongated element extending between a proximal end and a distal end, the distal end being affixed with respect to the end effector assembly to hold the first axis perpendicular to the elongated element,

a second elongated element extending between a second proximal end and a second distal end, the second distal end of the second elongated element being coupled with the end effector assembly so that rotation of the second elongated element about a second axis pivots the working member about the first axis, and

a drive assembly comprising a first drive member coupled to the proximal end of the elongated element and a second drive member coupled to the second proximal end of the second elongated element, the drive assembly configured to selectively operate the first drive member to rotate the elongated element and configured to selectively operate the second drive member to rotate the second elongated element,

wherein the elongated element and second elongated element are nested together, and wherein the elongated element is a first tube, the second elongated element is a second tube, and the elongated element and second elongated element are nested together so that one of the first tube and the second tube is disposed within the other of the first tube and the second tube.

**10**. The robotic surgical system of claim **9**, wherein the surgical instrument is movably coupled to the support arm.

**11**. The robotic surgical system of claim **9**, wherein the support arm is a robotic arm configured to move in response to an input control signal received from an input device operated by a user.

**12**. The robotic surgical system of claim **9**, wherein the working member is a blade.

**13**. The robotic surgical instrument of claim **9**, wherein the working member is configured to cauterize a tissue.

**14**. The robotic surgical instrument of claim **9**, wherein one or both of the elongate member and the second elongate member comprises a flexible portion.

**15**. The robotic surgical instrument of claim **9**, wherein one or both of the first and second drive members comprise a gear.

**16**. The robotic surgical instrument of claim **9**, wherein one or both of the first and second drive members rotate about a third axis offset from the second axis.

**17**. The robotic surgical instrument of claim **9**, further comprising an electrical wire extending through the second elongated element and coupled to the working member.

**18**. The robotic surgical instrument of claim **9**, wherein the second distal end of the second elongated element is coupled to the working member of the end-effector assembly via a gear.

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